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GEOLOGICAL SURVEY OF NEW JERSEY

FROM THE

ANNUAL REPORT OF THE STATE GEOLOGIST

FOR

1907

# Petrography of the Newark Igneous Rocks of New Jersey

BY

J. VOLNEY LEWIS

TRENTON, N. J.:
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1908

## PART IV.

# Petrography of the Newark Igneous Rocks of New Jersey.

By J. Volney Lewis.

# Petrography of the Newark Igneous Rocks of New Jersey.

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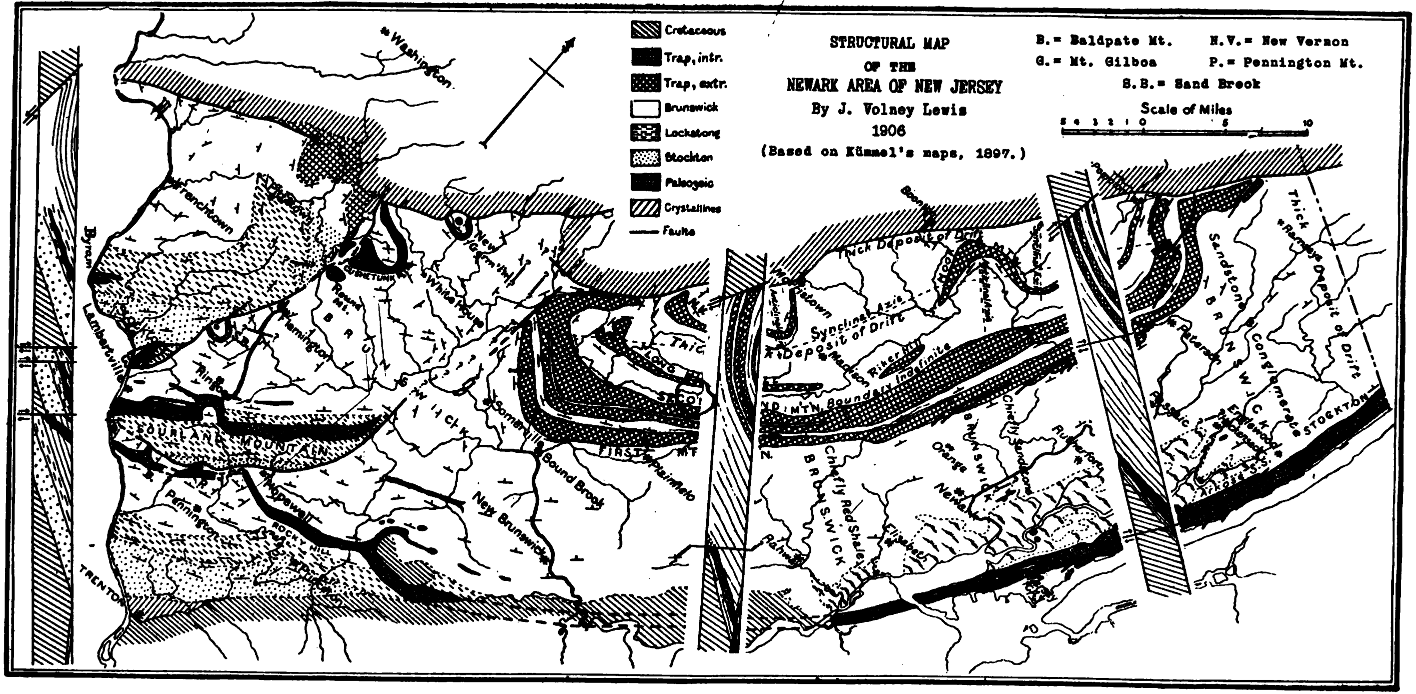
## SUMMARY OF PRINCIPAL TOPICS.

The "trap rocks," as they are commonly called, include two well-defined types; namely, the *intrusives* (diabases, gabbros, etc.), and the *extrusives* (chiefly basalts).

*The quartzose intrusive diabase,* which has about 100 miles of linear outcrop in New Jersey and New York, is a thick sheet or sill with prominent joints at right angles to the upper and lower surfaces, usually in a north-south direction, and sometimes cross-joints at right angles to them. The north-south joints are often developed into faults, usually of small displacement, but sometimes hundreds of feet. There is occasionally some curved and irregular jointing, but no columnar structure in the usual sense of that term. A horizontal sheeting or platy jointing is somewhat prominent, chiefly near the contacts, and a crumbling layer of olivine-diabase 10 to 20 feet thick appears about 50 feet above the base from Jersey City northward.

Megascopically the diabase is everywhere a dark gray heavy rock with greenish tints in the more altered, chloritic parts. In texture it is medium to coarse, with dense fine-grained and porphyritic facies at the contacts, and often for 40 or 50 feet above the base.

Microscopically the typical diabase consists of augite, plagioclase feldspars, quartz, orthoclase and magnetite, in the order of abundance, the first two usually in ophitic, though often in equant granular texture corresponding to diabase and gabbro, respectively,



Structural Map of the Newark Area of New Jersey.

and the next two in graphic intergrowth, sometimes constituting nearly one-half the bulk of the rock. Near the contacts micropegmatite disappears and olivine occurs in scattering crystals. In the olivine-diabase ledge olivine becomes abundant (up to 15 per cent. or more) as poikilitic inclusions chiefly in the feldspars. Minor constituents are biotite, apatite, pyrite, chalcopyrite and rutile. Augite and the feldspars are subject to a variety of alterations.

Chemically the rocks range from less than 50 per cent. to more than 60 per cent. of silica, generally with a corresponding variation in alumina, ferric iron and the alkalis, while ferrous iron, lime and magnesia vary inversely. The augite is rich in these latter constituents and poor in alumina, giving a great preponderance of the hypersthene and diopside molecules. The feldspars range from orthoclase and albite ($ab_{20}an_1$) to basic labradorite ($ab_3an_8$). Anorthoclase is doubtless present, as all feldspar analyses show potash.

Augite usually comprises about 50 per cent. of the rock (varying from 25 to 75); feldspars, 40 per cent. (20 to 45); quartz, 5 per cent. (0 to 20); ores, 5 per cent. (1 to 20), constituting a quartz-diabase, with normal diabase and olivine-diabase facies. In the quantitative system the rock is a graphi-ophiti-*camptonose* (III.5.3.4.), with *auvergnose* (III.5.4.4,5.), *dacose* (II.4.2.4.), and *tonalose* (II.4.3.4.) facies. The olivinic ledge is ophiti-poikili-*palisadose* ($IV,1^2,1^2,2$), a name proposed for a hitherto unnamed subrang.

Differentiation by gravity during crystallization, especially by the settling of olivine and the ores, and the rising of the lighter feldspars in the earlier and more liquid stages of the magma, with minor basic concentration at the contacts, perhaps by Soret's principle, satisfactorily accounts for the facies observed and their present relations.

Inclusions of long slabs of arkose in vertical position are found in the trap at several places. These are now in part *recomposed augite-granite*. Some of the augite constituents, however, appear to have been introduced from the inclosing magma.

Contact metamorphism has produced an elaborate series of hornfels characterized by various combinations of feldspar, biotite, quartz, augite, hornblende, tremolite, garnet, spinel, magnetite, muscovite, cordierite, scapolite, vesuvianite, sillimanite, andalusite, chlorite, calcite, analcite, titanite, tourmaline, zircon, apatite, and possibly leucite, the various types within the zone of metamorphism depending entirely on the original composition of the shales and not on relative distances from the contacts or degree of metamorphism. Metamorphic arkose, like the arkose inclusions, contains, besides orthoclase and plagioclase feldspars and usually some quartz, also augite, biotite, epidote, cordierite, chlorite, calcite, tourmaline and apatite.

*In the extrusive basalt* joints and horizontal lamination are much the same as in the intrusives, and often there is also a well-developed columnar structure. The sheets are probably composite, consisting of 3 or more flows in First and Third Mountains, and 2 or 3 in Second Mountain, the successive flows or pulsations varying slightly in character.

Vesicular and ropy flow-structure are abundant at the upper surfaces of the various flows, and portions are often rolled under the bottom. A breccia at Little Falls is probably due to flow of the lava into a local body of water on a plain of continental deposition. A tuff bed that was cut in the tunnel of the Jersey City pipe line through Hook Mountain consists of fragments of volcanic glass containing minute crystals of feldspar, augite and olivine, and the interstitial spaces are filled with analcite.

Microscopically the rock varies from a brownish structureless or spherulitic glass to a fine-grained granular or ophitic augite-plagioclase-rock with magnetite grains and occasional olivine crystals. Frequent phenocrysts of augite, and less commonly of feldspar, represent an earlier stage of crystallization.

Chemically the basalt is less variable in composition than the diabase, although very similar to it. Small and apparently characteristic differences are found between the successive parts of the various sheets which it is thought possibly represent successive flows. To a certain extent these parts are also different in physical characters. The Third Mountain basalt is notably more basic than that of First Mountain, and lower in alumina, magnesia and lime, but higher in soda, titanium oxide, and much higher in iron.

The rock is *basalt* and *basalt-porphyry,* both glassy and holocrystalline, and often has a diabasic or ophitic texture. In the quantitative classification the analyses fall into the following subrangs: *camptonose* (III.5.3.4.); *ornose* (III.5.3.5.); *auvergnose* (III.5.4.4,5.).

Small inclusions are found in the base of First Mountain, and probably also in the others, consisting of sandstone or shale fragments up to 2 or 3 inches in diameter, which are baked into a hard jaspery condition. An oval sandstone mass, 2 by 4 feet, apparently unaltered, was found in the Third Mountain sheet at Pompton. The only microscopic changes noticeable in the smaller inclusions are a darkening of the red color and the development of crystalline calcite, both chiefly within 2 or 3 millimeters of the contact. Contact effects on the underlying strata are of a similar character where found at all. Often no change whatever is apparent.

The shale 1 to 2½ feet beneath the First Mountain basalt, around the curved southwestern portion, is mottled by partial bleaching and rendered porous by the removal of small calcite crystals which this rock usually contains. In the spaces native copper and chalcocite have been deposited. Nothing comparable to this is found under the other sheets, nor under other portions of this one. The effects are attributed to ore-bearing solutions, probably magmatic waters, that brought up the copper from the intrusive sheet of Palisade diabase below.

## INTRODUCTION.

The following paper considers specially the mineral and chemical characters of the igneous rocks (commonly called trap) of the Newark (Triassic) formation, and is thus supplementary to the studies on these rocks that were published in the last Annual Report.[1]

It is only necessary here to recall the location of the belt of Newark red shales, sandstones, etc., which forms an area of about 1,400 square miles across the north central portion of the State, and the distribution of the igneous rocks within it, as shown by the map (Plate X.). The soft shales and sandstones are consolidated beds of mud and sand that were long ago washed over this region. The hard, blackish, igneous rocks are in sharp contrast with these, not only in physical characters, but in origin as well. As the name igneous indicates, they have cooled in their present position from

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[1] J. Volney Lewis, "Origin and Relations of the Newark Rocks," Annual Report of the State Geologist for 1906, pp. 99–129.

a molten condition; some as lava flows or *extrusives* (basalt) that spread over the surface, while others, the *intrusives* (diabase, gabbro), were injected into fissures or spread between the strata of the shales and sandstones. These two types are distinguished on the map, and both are extensively represented in the State, the outcrops of intrusive diabase having a linear extent of about 70 miles and covering an area of about 60 square miles, while the corresponding dimensions for the extrusive basalt are 140 miles and over 100 square miles, respectively.

On account of their great resistance to the decomposing influences of the weather, all of the larger masses of these rocks form prominent ridges. The three great extrusive sheets form the Watchung or Orange Mountains and smaller ridges in the vicinity of Flemington, New Germantown and Sand Brook. The intrusives have given rise to the prominent ridge of the Palisades, along the Hudson River, and to Rocky Hill, Sourland, Pennington, Baldpate, Cushetunk and Round mountains, besides a number of smaller prominences. There are also many thin sheets and dikes associated with the larger intrusives, but they are too small to have any notable effect on the topography.

It is noteworthy that the igneous rocks, both intrusive and extrusive, are confined strictly to the area of Newark or Triassic rocks. If any of the dikes penetrated the adjacent areas of older rocks, their continuity has not been traced, and any surface flows that may once have overlapped these areas have since been removed from them by erosion. There is but one small exception to this statement known in New Jersey. Eight miles west of Bernardsville an outcrop of coarse-grained diabase occurs for a short distance in the road as it ascends a hill three-quarters of a mile west of Pottersville. The surrounding rocks are the crystalline gneisses of the Highlands, although the border of the Newark area is very near. Other exposures were not found in the immediate vicinity, and hence the extent of this rock is not known, although it is evidently not great. In thin section this rock is identical in composition and texture with the typical Palisade quartz-diabase and that of Cushetunk Mountain. The latter is 7 miles to the southwest, although the extrusives of New Germantown are only 3 miles distant. This rock is from a magma identical with that of the Newark intrusives, and there can be little doubt that it is part of the same material.

Fig. 1. Cylindrical jointing on the face of the Palisades at Alpine.

Fig. 2. Cylindrical jointing on top of Palisades near Coytesville. (Photograph by G. E. Ashby.)

Small diabase dikes are not infrequently found intersecting the crystalline rocks in many parts of the Highlands, and it is not improbable that many of these are of the same age and origin as those of the Newark area.

### INTRUSIVE ROCKS.

The writer has previously shown[1] that, with the possible exception of Cushetunk and Round mountains, all of the larger bodies of intrusive rocks in the State are to be correlated with the great mass of the Palisades, and are continuous with it, except where subsequently cut off by faulting. This is borne out not only by the structural relations, which were made the basis of the correlation, but also by their mineral and chemical characters, as described below. In accordance with this unity of origin and petrographic characters, the term *Palisade diabase* is here used in a generic sense, including all of the various connected intrusives, as indicated on the map (Plate X.).

### INTRUSIVE DIABASE.

*Definition.*—Diabase is a rock composed essentially of the minerals augite and plagioclase feldspar, with minor amounts of magnetite, and sometimes a little olivine (chrysolite) and biotite. It is distinguished from other rocks of like composition by the characteristic diabasic or ophitic texture; that is, the feldspars are usually developed in interlacing rod-like and lath-shaped crystals, and the augite fills the irregular spaces between (Plate XV.). This texture results from a reversal of the usual order of crystallization as the rock cooled and solidified, the slender feldspars completing their crystals first and leaving the augite to accommodate itself to the irregular outlines of the interstices, or, if greatly in excess, to form a ground mass in which the feldspars are imbedded.[2] The coarser-grained portions, however, often develop an even granular texture, and thus pass into gabbro.

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[1] J. Volney Lewis, Annual Report State Geologist for 1906, pp. 117–121; Bull. Geol. Soc. of Amer., Vol. 18, pp. 204–207, 1907.

[2] Diabasic and ophitic are often used interchangeably, but sometimes a desirable distinction is made (as by Professor Kemp in his Handbook of Rocks) by applying the former term to the case in which the augite forms an interstital filling, and the latter to that in which the feldspars are imbedded in an augite ground mass (Plate XLVI.).

*Distribution.*—The intrusive diabase is typically developed in the Palisades, along the Hudson River, from Haverstraw, N. Y., southward to Jersey City. As a less conspicuous ridge it continues, however, south of Jersey City to Bergen Point and across Staten Island to Fresh Kills, opposite Carteret, N. J. From this point it is covered for a distance of 20 miles by the sands and clays of the Cretaceous formation, to the vicinity of Deans, 5 miles southwest of New Brunswick. Westward from there it forms, successively, Rocky Hill, Pennington, Baldpate and Sourland mountains, and the trap mass at Byram, making a total length of outcrop in New York and New Jersey of about 100 miles.

*Structure.*—The diabase is a massive sheet or sill hundreds of feet in thickness intruded between strata of shales and sandstones. Its most prominent structure is the jointing developed at right angles to its upper and lower surfaces (Plates XXI., Fig. 2; XXII., Fig. 2; XXIX., Fig. 1). Since the rock usually dips 10 to 20 degrees toward the northwest, like the strata above and below it, these joints are not quite vertical, but are tilted backward a little, as seen in the cliffs along the Palisades. The more prominent joints usually lie in a north-south direction, N. 20° E., or N. 45° E., in various localities and at right angles to these directions. They are usually quite pronounced in one particular direction, with less prominent jointing at right angles, and sometimes two or more sets of joints are developed together, with minor cracks traversing the rock irregularly. Sometimes, also, jointing of a distinctly curved, cylindrical form is observed (Plate XI., Figs. 1 and 2), giving rise to rounded columns. Other forms of concentric jointing occasionally occur (Plate XII., Fig. 1).

Another structure, less pronounced, but still quite noticeable, is a sheeting or platy jointing parallel to the upper and lower surfaces. These partings are often as near together as one to 4 or 5 feet in the finer-grained portions of the rock near the contacts with the inclosing strata, but they are much less frequent in the coarser-grained rock that constitutes the main mass. A very minute parallel banding or flow-structure is occasionally observed near the contacts, and is sometimes quite noticeable in thin sections without the microscope.

The result of these structures on exposed cliffs of the diabase, like the Palisades, formed by the breaking away of masses of the rock along these natural cracks, is the production of a pronounced vertical columnar appearance, where two or more directions of

Fig. 1. Concentric jointing in diabase, Pa. R. R. cut, Jersey City.
(Orphans' Home, beyond, is built of diabase.)

Fig. 2. Faulting in the Palisades, in an old quarry at Guttenburg.

jointing are well developed, or of broad vertical sheets or slabs where only one direction is prominent. Rounded columnar masses sometimes appear as a result of the cylindrical jointing. True columnar structure, however, such as is beautifully developed in many parts of the extrusive rocks of the Watchung Mountains (Plates XXXV. and XXXIX.), is not the result of intersecting continuous joint planes, and is nowhere found in the intrusives.

A crumbling, deeply-weathered layer of olivine-diabase, 10 to 20 feet thick (Plate XIX.), appears in many places along the Palisades for about 20 miles north of Jersey City. It is approximately horizontal, and usually about 40 or 50 feet above the base of the sheet. In many places this ledge, which is invariably coarse-grained, is the first rock of that texture encountered above the base, all below it being quite dense and fine-grained, but this is not without exceptions.

Sometimes the vertical north-south joint-planes have also been planes of slipping or faulting, and contain from an inch or two up to 3 or 4 feet of soft, crushed and decomposed rock. In many cases the frequent repetition of such fault-planes near together has produced *shear-zones* of considerable width, in which the solid rock is thinly sheeted between the vertical layers of softer materials. Veins of calcite, quartz, feldspar, zeolites, and more or less pyrite, chalcopyrite, galenite and sphalerite, are often formed in these fault-planes, but the bulk of the material that they contain is a mass of soft, slippery, greenish-black chloritic minerals, resulting mainly from the decomposition of augite in the crushed rock (Plate XII., Fig. 2). Veinlets of calcite and feldspar also occasionally traverse the solid rock irregularly, but they are insignificant in size and frequency.

*Megascopic characters.*—The diabase is everywhere a dark colored heavy rock, and in the main coarse-grained, the individual minerals being often more than one-eighth of an inch in diameter. On account of its distinctly granular character it is sometimes called granite, although it is a much darker and heavier rock than true granite. The dark green, nearly black, color of the augite, which is the most abundant constituent, and the black grains of magnetite, with the grayish translucent feldspars, give a dark greenish or bluish-gray color to the rock. The color changes to brighter shades of green as the augite becomes more hydrated, and hence the freshly-broken rock in quarries and other excavations presents some variety of appearance, although always dark.

## EXPLANATION OF PLATE XIII.

*Photomicrographs of thin sections.*

Fig. 1. Diabase, *Coytesville.* Magnified 18 diameters. The coarse granular (gabbroic) rock immediately above the olivine-diabase ledge, at the east end of the old quarry. The white areas are feldspar, the gray augite, and the black aggregates are iron oxides from incipient alteration of augite. Patches of micropegmatite (quartz and orthoclase intergrown) appear indistinctly near the top of the figure. Thin section No. 303–L.

Fig. 2. Olivine-diabase, *same locality.* Magnified 18 diameters. The larger grains are feldspar (white) and augite (gray) in granitic texture; the smaller grains, sprinkled plentifully through the feldspars and occasionally in the augite and broken by numerous cracks are olivine. The black crystals and grains are titaniferous magnetite, some of which are surrounded by a thin sheath of biotite. Thin section No. 304–L.

Fig. 3. Diabase, *same locality.* Magnified 18 diameters. The coarse-grained rock immediately below the olivine-diabase shown in Fig. 2. Consists chiefly of augite (gray) and feldspar (white), with occasional olivine partly altered to bright yellow serpentine. A large oblong olivine grain, with serpentine and black oxide granules on one side, occupies the center of the field. The small black grains are magnetite. Thin section No. 302–L.

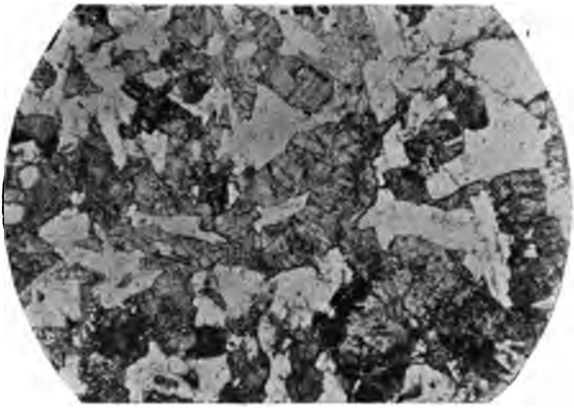

Fig. 1.

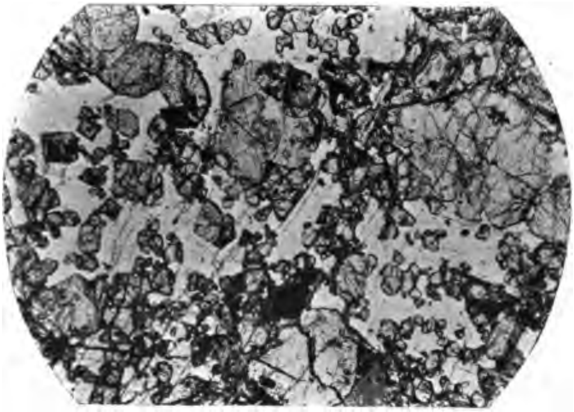

Fig. 2.

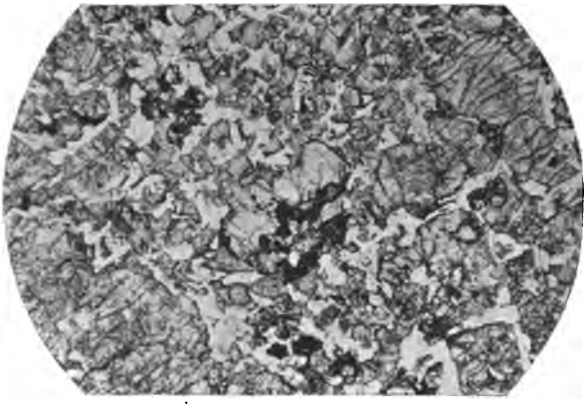

Fig. 3.

Near the contacts with the overlying and underlying strata of shales and sandstones the texture becomes very fine-grained, often with porphyritic crystals of augite and less frequently feldspar, and the rock is very much like the dense extrusive basalt of the Watchung or Orange Mountains. This is particularly noticeable in the basal portions of the palisade diabase, where rock of this character is often 40 or 50 feet in thickness, changing, sometimes gradually, sometimes suddenly, into the coarser-grained facies above. Often this transition occurs at the base of the crumbling olivine-diabase referred to above, but sometimes below it.

*Microscopic characters.*—When examined in thin sections under the microscope the intrusive rock is found in all cases to contain augite, plagioclase feldspar, magnetite and a little apatite. There are also almost universally some quartz and orthoclase in micrographic intergrowths (Plate XIV.), and these minerals sometimes constitute as much as one-half the bulk of the rock.[1] Less commonly olivine (chrysolite) and biotite are also present in small amounts, and rarely scattering grains of pyrite and chalcopyrite and slender needles of rutile.

The texture of the rock is usually diabasic or ophitic, as explained above; that is, the augite fills the interstices between the interlacing lath-shaped feldspars, or, when greatly in excess, it forms the ground mass in which the feldspars are imbedded (Plate XV.). In the coarser-grained portions of the rock, however, a granitoid texture is often developed, in which the two chief minerals are formed in grains of approximately equal size and of nearly equal dimensions in every direction, constituting a true gabbro (Plate XIII.). In the dense contacts also, the larger

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[1] It is noteworthy that one of the results of the British Antarctic expedition, just published, is the discovery of large bodies of a quartz-diabase (dolerite) almost identical in character with that of the great Newark intrusive here described, in King Edward VII. Land, in S. lat. 770° 45′ and E. long. 163°, where it is intrusive in sandstones and granites of undetermined age in the Kukri Hills. "A characteristic feature of most of these dolerites is the presence in patches and in the interstices of the augite and feldspar, of more acid material, showing quartz in radiating (spherulitic) and micropegmatitic intergrowth with feldspar. In the section * * * quarts is seen to have crystallized round prisms of feldspar, from the end of which springs a micropegmatitic intergrowth." *National Antarctic Expedition, Natural History, Vol. I.;* London, 1907, *Petrography,* by G. T. Prior, p. 136.

The analysis of this rock (No. XVI., p. 121) shows a similar correspondence with much of the New Jersey diabase, except in its somewhat higher lime content.

augites and occasional olivines and feldspars scattered through a fine-grained ground mass of feldspar rods, augite and magnetite grains, constitute a basalt-porphyry facies.

Augite, the most abundant constituent, is pale greenish to colorless in the section and sometimes exhibits a slight pleochroism, pale green to light yellow. It occurs in large plates, up to 3 or 4 millimeters in diameter, and in irregular grains whose form is determined by the accompanying feldspars. Crystal outlines are rarely observed. In the finer grained portions near the contacts, augite of two generations usually appears, the earlier as large porphyritic plates scattered through the denser ground mass in which the augite of later crystallization forms a fine granular filling between the feldspars. The augites often show the two forms of pinacoidal twinning, both frequently appearing in the same specimen. That parallel to the orthopinacoid (100) generally produces paired halves, while the basal twinning, parallel to (001), is more commonly repeated in thin lamellae which are sometimes exceedingly minute (Plate XV., Figs. 2, 3). In addition to these there is also an interpenetration twinning that produces an effect between crossed nicols very similar to micrographic intergrowth of quartz and orthoclase (Plate XV., Fig. 3). (For composition of the augite, see analyses page 117.)

Augite sometimes incloses magnetite grains and biotite. Apatite is also occasionally included, but it is found chiefly in the feldspars and quartz. Augite, in several adjacent areas, is often similarly oriented, giving rise to a large individual that incloses numerous slender feldspars. This structure, which is not uncommon in these rocks, has been called micropoikilitic.

Alteration, to a greater or less degree, is nearly always observed in the augite, the earliest traces of it being seen in the dirty greenish to brownish tints assumed, and the slight accompanying decrease in transparency. Three modes of alteration are observed, but one of these usually greatly predominates in any given locality. In the order of their frequency, and designated by their resulting products, these are (1) *chloritization*, or alteration into green chlorite in confused scales or radial clusters; (2) *uralitization*, or change of the augite into pale green fibrous amphibole, oriented with the vertical axis parallel to that of the parent mineral. Along with uralite, more or less secondary biotite is also frequently formed. A second step is often observed whereby the uralite and biotite are in turn altered into chlorite. (3) *Serpentinization,* a process usually beginning in the central portions, by which the augite changes into yellow or brownish yellow, confusedly fibrous serpentine, is less commonly seen. In all of these modes of alteration, black iron oxides are usually deposited in the midst of the secondary mineral. These appear as granular aggregates or as trellis-like skeleton crystals of magnetite, and are sometimes so numerous as to render black and opaque almost the whole of the space originally occupied by the augite. Calcite is rarely found among the products in thin sections, even in the most thoroughly decomposed specimens.

Plagioclase, the chief feldspathic constituent and the second mineral in abundance, occurs characteristically in elongated, relatively narrow forms. In some of the coarser textured rock the elongation is less pronounced than in the finer grained facies, ranging up to 2 millimeters in length, with a breadth as much as one-fifth to one-third as great. These dimensions become more nearly equal in the coarsest textures, with diameters of 3 to 4 millimeters in the granitoid facies of the rock. Often the plagioclase presents complete crystal outlines, but very commonly the terminal planes are lacking, the elongated crystals abutting against each other irregualrly. They are universally made up of thin twinning lamellae, chiefly according to the albite law, but pericline and carlsbad twinning also frequently occur. Zonal structure, consisting of shell-like layers of more and more acid composition from the center outward, is quite commonly developed, and fringing the extreme acid borders a graphic intergrowth of orthoclase and quartz is often found (Plate XIV.).

Maximum extinction angles in sections normal to the albite twinning-plane usually range a little under 30°, corresponding to an acid labradorite. Analyses of the feldspar (see p. 118) have shown that labradorite containing the soda and lime molecules in about equal proportions, is the most abundant plagioclase, but that other members of the series, ranging up to almost pure albite, the soda feldspar, are present in considerable amount.

Plagioclase often incloses minute apatite crystals in considerable numbers, and olivine when present, but seldom any other original constituent. In altering, it usually does not form opaque masses

## EXPLANATION OF PLATE XIV.

*Photomicrographs of thin sections.*

Fig. 1. QUARTZ-DIABASE, *Homestead.* Magnified 18 diameters. From the Pa. R. R. tunnels, 400 feet from the western portal. Consists of coarse-grained feldspar and augite in a matrix of micropegmatite. The large feldspars are considerably altered and appear dark gray in the figure. The augite shows parallel cleavage and irregular cracks. The quartz of the micropegmatite and the larger separate crystals and grains of the same mineral are bright and clear. Thin section No. 315–L.

Fig. 2. QUARTZ-DIABASE, *Pa. R. R. cut 420 feet east of Marion Station, Jersey City.* Photographed with crossed nicols; magnified 18 diameters. The large elongated crystals are striated feldspars, around one of which the area of micropegmatite is clustered. Augite grains appear below the center and near the bottom of the figure. Thin section No. 15–L.

Fig. 1.

Fig. 2.

of kaolinite, although more or less of this is commonly seen, but changes chiefly into fine scaly and confused fibrous masses of colorless mica, probably paragonite or muscovite. Often, when the accompanying augite is altering into chlorite, this mineral is also found developing in minute scales in the plagioclase, owing to migration of iron and magnesia from the decomposing augite.

Orthoclase and quartz, as noted above, usually occur as a fringe or border about the plagioclases, where, in graphic intergrowth, they constitute a micropegmatite that fills many of the triangular and irregular interstices (Plate XIV.). These areas are often small and sparingly scattered through the sections, but they are usually quite a prominent constituent, and are sometimes as much as 3 or 4 millimeters across. In the latter case they are distinctly visible, even in the hand specimen, as in the western portions of the Pennsylvania railroad tunnels at Homestead, where in some of the coarse, granitic facies they constitute about one-half the bulk of the rock. Individual grains of quartz and orthoclase, and occasional microperthite up to 1 millimeter in diameter, are also observed in some instances. In many cases the apatite inclusions in the quartz-orthoclase intergrowths are strikingly abundant, sometimes to their almost total exclusion elsewhere.

Orthoclase is usually much more altered than plagioclase, being often chalky and nearly opaque from the formation of kaolinite. In more extreme cases the mineral gives place entirely to a mass of kaolinite stained brownish with iron oxides from the augite, or to a mixture of such material with secondary chlorite and magnetite from the same source. This condition is observed even in the presence of nearly fresh plagioclase (Plate XIV., Fig. 1).

Magnetite is always present, but in greatly varying amounts. Often only a few scattering small grains will be seen, but, on the other hand, it is frequently so abundant as to give a decidedly black color to the rock, and it then appears thickly sprinkled through the section. Crystals of magnetite are sometimes observed (Plate XV., Fig. 2), but most of the masses, like the augites, are irregularly molded or grouped in clusters of small grains between the plagioclase feldspars. It often partly incloses both the plagioclase and the augite (in such cases probably secondary), but is also sometimes inclosed in the latter. Magnetite is generally in smaller masses than these constituents, but in this respect also it is very variable.

## EXPLANATION OF PLATE XV.

*Photomicrographs of thin sections.*

Fig. 1. Diabase, *½ mile south of Rocky Hill.* Photographed with crossed nicols; magnified 18 diameters. From the quarry near the middle of the intrusive sheet. Shows typical diabasic texture, and several small areas of micropegmatite appear indistinctly near the center of the field. Thin section No. 42–L.

Fig. 2. Diabase, *Wayne St. and Mill Road, Jersey City.* Photographed with crossed nicols; magnified 52 diameters. Typical diabasic texture. Large augite to the right shows combined orthopinacoidal and multiple basal twinning. Micropegmatite occupies large areas in the lower central portion of the field, with an elongated octahedral crystal of magnetite. Thin section No. 22–L.

Fig. 3. Diabase, *Devil's Half Acre, near the northeast end of Sourland Mountain.* Photographed with crossed nicols; magnified 55 diameters. Shows striated plagioclase feldspars and diabasic texture. The large central augite crystals show a combination of orthopinacoidal, multiple basal, and interpenetration twinning. Thin section No. 13–L.

Fig. 1.

Fig. 2.

Fig. 3.

Secondary magnetite from the alteration of augite and olivine is found in granules and aggregates through the decomposition products of these minerals, and sometimes clustered about the original magnetite grains. Secondary magnetite being one of the first products of incipient decomposition of the augite, it is almost universally present in greater or less amount, and it is often quite impossible to distinguish it with certainty from magnetite of primary origin. It seems quite probable, however, that the masses of magnetite molded about the feldspars and augites described above are largely secondary.

Biotite is often present in small amount, especially in the finer-grained contact facies of the diabase, and is sometimes clustered about the magnetite of the coarser-grained rock in large irregular flakes. It is strongly pleochroic, deep reddish-brown for light polarized parallel to the cleavage, and light yellow at right angles to this direction. In diagonal position a distinct purplish tinge is shown. Biotite is also often secondary after augite, and is itself partly altered in turn to green chlorite.

Olivine is entirely absent from the great bulk of the Palisade diabase. It occurs in small amounts, however, near the contacts with the inclosing strata, both above and below (Plate XVI., Fig. 2), and is exceptionally abundant in the olivine-diabase ledge of the Palisades, constituting as much as 15 per cent. of the whole. In the finer-grained border facies of the rock olivine occurs in scattering porphyritic crystals, which sometimes exhibit resorption phenomena in rounded and embayed outlines. Corrosion mantles or "reaction rims" of radial enstatite sometimes surround the larger crystals (Plate XVI., Fig. 2), and nest-like aggregates entirely replace some of the smaller ones. In these fine-grained portions of the rock olivine is usually altered, wholly or in part, to yellowish or yellowish-brown serpentine. In striking contrast with this, it is found in the olivine-diabase ledge, in numerous perfectly fresh crystals and irregular grains, which are inclosed largely in the feldspars, though occasionally also in the augite (Plate XIII., Fig. 2). As compared with the coarse-grained texture of this rock, the olivines are relatively small, ranging up to 0.3 millimeter by 0.7 millimeter in prismatic sections, which is less than one-fourth the usual size of the augite and feldspars. They also retain a striking freshness and transparency even when the augites have reached an advanced stage of alteration.

## EXPLANATION OF PLATE XVI.

*Photomicrographs of thin sections.*

Fig. 1. Basaltic diabase, *west end of the N. Y., S. & W. R. R. tunnel through the Palisades, near Fairview.* Magnified 42 diameters. The fine-grained porphyritic facies at the contact, showing the diabasic texture of the dense groundmass of elongated feldspars and granular augite. Augite phenocrysts appear to the left. Thin section No. 85–L.

Fig. 2. Diabase, *same thin section as Fig. 1.* Magnified 42 diameters. Shows a serpentine pseudomorph of a large olivine phenocryst in the middle, surrounded by a thick sheath of fine-grained enstatite, biotite and magnetite.

Fig. 3. Diabase, *just north of Granton.* Magnified 42 diameters. Fine-grained rock near the bottom contact in the quarry. Shows a rounded, unstriated feldspar in the center, surrounded by a mantle of augite, biotite and black oxide granules. Nest-like aggregates of these minerals occur in other parts of the section without the central remnant of feldspar. Thin section No. 62–L.

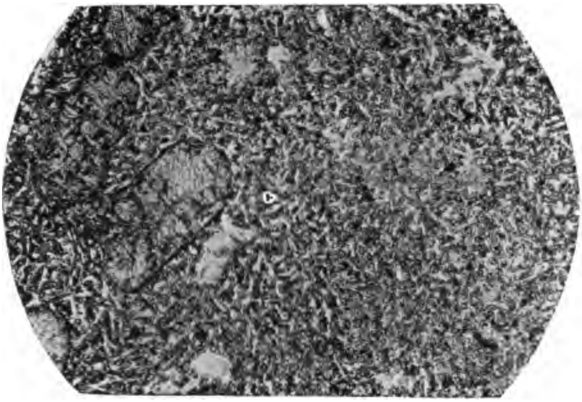

Fig. 1.

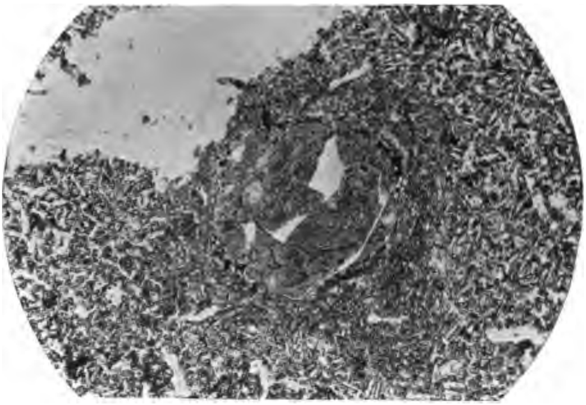

Fig. 2.

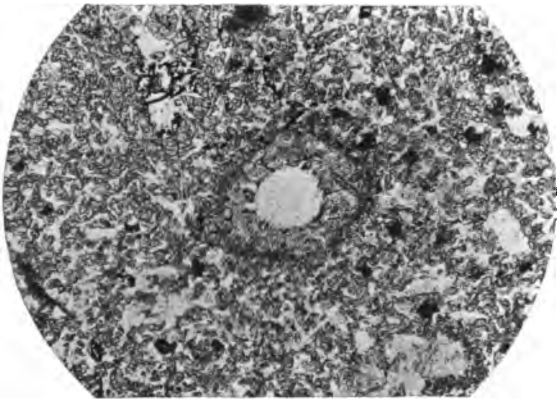

Fig. 3.

Apatite, which has been named as an inclusion occuring chiefly in the feldspars and quartz, is always in well formed prismatic crystals, ranging from very minute up to 1 millimeter in length and 0.06 millimeters in diameter, a size prominently visible with even the lowest powers of the microscope. It is always most abundant in the feldspars and quartz, sometimes chiefly in the plagioclase, sometimes in the quartz-orthoclase intergrowths, and seldom occurs in the other constituents.

Pyrite and chalcopyrite are rarely seen in the thin sections of the diabase. Rutile occurs occasionally in minute slender needles in the micropegmatite, but it has been found in relative abundance in only one place, namely, in the coarse trap adjacent to the sandstone inclusion at Marion, Jersey City. Here the minute slender needles in radial tufts and confused tangled aggregates, are quite numerous in the graphic intergrowths of quartz and orthoclase.

*Composition of the Augite.*—Analyses of the augite from this rock at Rocky Hill[1] and from the similar intrusive diabase at West Rock, New Haven, Conn.,[2] yielded the following results:

*Analysis of augite from the intrusive diabase.*

| | I. | II. | III. |
|---|---|---|---|
| $SiO_2$ | 47.72 | 48.54 | 50.71 |
| $Al_2O_3$ | 3.44 | 5.50 | 3.55 |
| $Fe_2O_3$ | 5.93 | 2.77 | n.d. |
| FeO | 18.34 | 21.25 | 15.30 |
| MgO | 12.89 | 7.67 | 13.63 |
| CaO | 11.40 | 10.97 | 13.35 |
| $Na_2O$ | 0.86 | | |
| | | 3.10 | 1.48[3] |
| $K_2O$ | 0.37 | | |
| MnO | n.d. | n.d. | 0.81 |
| Ign. | 0.00 | 0.82 | 1.17 |
| | 100.95 | 100.62 | 100.00 |

I. Rocky Hill. Quarry near the middle of the trap. A. H. Phillips, analyst. (Rock analyses No. XIII., p. 121.)

II. Rocky Hill. Old quarry near station, about 420 feet from the upper contact. A. H. Phillips, analyst. (Rock analysis No. XI., p. 121.)

III. New Haven, Conn. From West Rock, a very similar intrusive diabase. G. W. Hawes, analyst. (Rock analysis No. XIV., p. 121.)

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[1] A. H. Phillips, Am. Jour. Science, Vol. VIII., 1899, p. 267.

[2] G. W. Hawes, Am. Jour. Science, Vol. IX., 1875, p. 185.

[3] By difference.

In the great excess of ferrous iron and magnesia over lime, alumina and ferric iron, these analyses indicate quite exceptional composition for augite, corresponding to combinations of the hypothetical pyroxene molecules in the following proportions:

[*ao*=acmite, $NaFe(SiO_3)_2$, *hy*=hypersthene, $(Mg,Fe)SiO_3$ *di*=diopside, $Ca(Mg,Fe)(SiO_3)_2$, *al*= $(Mg,Fe)(Al,Fe)_2SiO_6$.]

ac hy di al ac hy di al ac hy di al
I. 108 : 640 : 816 : 159 = 1 : 5.93 : 7.56 : 1.47 = (approx.) 2 : 12 : 15 : 3
II. 270 : 530 : 784 : 81 = 3.33 : 6.54 : 9.68 : 1 = " 7 : 13 : 19 : 2
III. 126 : 522 : 956 : 69 = 1.83 : 7.72 : 13.86 : 1 = " 2 : 8 : 15 : 1

*Composition of the Feldspar.*—Analyses of the feldspars have also been made from the same localities, Rocky Hill,[1] N. J., and West Rock,[2] New Haven, Conn., with the following results:

*Analyses of Feldspars from the Intrusive Diabase.*

| | I. | II. | III. | IV. | V. | VI. | VII. | VIII. |
|---|---|---|---|---|---|---|---|---|
| Sp. Gr. | >2.69 | <2.69 | >2.69 | <2.69 | <2.60 | =2.577 | >2.69 | <2.69 |
| $SiO_2$.......... | 53.84 | 62.26 | 66.84 | 71.68 | 66.28 | 66.79 | 52.84 | 60.54 |
| $Al_2O_3$........ | 29.30 | 21.87 | 17.98 | 15.02 | 16.79 | 19.36 | 28.62 | 24.11 |
| $Fe_2O_3$ ....... | 0.81 | 0.54 | 2.60 | 2.48 | 1.60 | 0.91 | 1.52 | 1.14 |
| MgO.......... | 0.28 | 0.15 | 0.48 | 0.12 | 0.13 | 0.13 | 0.46 | 0.27 |
| CaO........... | 10.08 | 6.53 | 5.02 | 3.86 | 0.71 | 0.80 | 11.81 | 9.15 |
| $Na_2O$......... | 5.31 | 7 98 | 5 46 | 5.52 | 9.76 | 7.34 | 2.38 | 4.11 |
| $K_2O$.......... | 1.16 | 1.20 | 1.72 | 1.37 | 5.31 | 4.95 | 0.86 | 1.06 |
| Ign............ | 0.44 | 0.32 | 0.72 | 0.00 | 0.49 | ......... | 1.06 | 0.59 |
| | 101.22 | 100.85 | 99.82 | 100.05 | 101.07 | 100.28 | 99.55 | 100.97 |

I., II. Rocky Hill. Quarry near the middle of the trap. A. H. Phillips, analyst. (Analysis of the rock, No. XIII., p. 121.)

III., IV., V., VI. Rocky Hill. Old quarry near station. A. H. Phillips, analyst. (Rock analysis No. XI., p. 121.)

VII., VIII. New Haven, Conn., West Rock. G. W. Hawes, analyst. (Rock analysis No. XIV., p. 121.)

Nos. I. and II. constituted 32.2 per cent. and 14.3 per cent., respectively, of the rock from which they were separated. Nos. III. to VI. occurred in the following amounts: Specific gravity above 2.69, 23.1 per cent.; below 2.69, 13.4 per cent.; below 2.60, 6.5 per cent.

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[1] A. H. Phillips, Loc. cit.

[2] G. W. Hawes, Loc. cit.

Reckoning the potash as orthoclase, and assigning soda and lime to the end molecules of the plagioclase series, albite and anorthite, these analyses correspond to the following mineral composition:

*Mineral Constitution of the Feldspars.*

| | I. | II. | III. | IV. | V. | VI. | VII. | VIII. |
|---|---|---|---|---|---|---|---|---|
| Quartz ........... | 0.0 | 0.0 | 20.6 | 23.0 | 6.4 | 2.4 | 7.7 | 11.0 |
| Orthoclase ...... | 7.1 | 7.2 | 10.0 | 8.2 | 24.8 | 30.0 | 5.0 | 6.1 |
| Albite .... ...... | 44.5 | 67.1 | 45.8 | 46.0 | 62.3 | 60.8 | 20.5 | 34.4 |
| Anorthite. | 43.1 | 19.8 | 19.8 | 11.2 | 3.3 | 3.9 | 58.5 | 43.7 |
| Augite .. ........ | 0.0 | 5.0 | 0.0 | 7.0 | 0.8 | 0.0 | 0.0 | 1.3 |
| Ores ............. | 0.1 | 0.0 | 2.6 | 1.6 | 1.4 | 0.9 | 1.3 | 0.5 |
| Kaolin .......... | 3.2 | 0.0 | 0.0 | 0.0 | 0.0 | 1.7 | 5.7 | 2.5 |
| Carbonates ..... | 2.0 | 0.9 | 1.2 | 0.0 | 1.0 | 0.3 | 1.3 | 0.5 |

Omitting the non-feldspathic constituents, and recalculating to 100 per cent., the following values are obtained:

| | I. | II. | III. | IV. | V. | VI. | VII. | VIII. |
|---|---|---|---|---|---|---|---|---|
| Orthoclase .... | 7.5 | 7.7 | 13.2 | 12.6 | 27.4 | 31.7 | 6.0 | 7.2 |
| Albite .......... | 47.1 | 71.3 | 60.6 | 70.3 | 68.9 | 64.2 | 24.4 | 40.9 |
| Anorthite....... | 45.4 | 21.0 | 26.2 | 17.1 | 3.7 | 4.1 | 69.6 | 51.9 |

Designating the albite molecule, $NaAlSi_3O_8$, by *Ab*, and the anorthite molecule, $CaAl_2Si_2O_8$, by *An*, the soda-lime constituents correspond very nearly to the following molecular ratios:

I. $Ab_1$ $An_1$=Labradorite.
II. $Ab_7$ $An_2$=Oligoclase.
III. $Ab_3$ $An_2$=Andesine.
IV. $Ab_4$ $An_1$=Oligoclase.
V. $Ab_{20}$ $An_1$=Albite.
VI. $Ab_{17}$ $An_1$=Albite.
VII. $Ab_3$ $An_8$=Labradorite.
VIII. $Ab_5$ $An_6$=Labradorite.

*Order of crystallization.*—From the prevailing diabasic or ophitic texture of the intrusive diabase it is evident that the crystallization of the plagioclases was quite generally completed before that of the augite. In the granitoid portions of the rock, however, they have formed more nearly simultaneously, each interfering with the crystal outlines of the other. Moreover, the presence of numerous plates of porphyritic augite in the fine-grained contact facies of the rock, with only rarely a large feldspar, indicates that crystallization had begun before intrusion under conditions that would have led to the formation of the minerals in their usual order in igneous rocks, namely, the augite before the feldspars. Olivine, as shown by its crystalline form and by its indifference to the other constituents, was one of the first minerals to crystallize; orthoclase and quartz were the last. Apatite has usually been formed very early, as shown by its frequent abundance in the plagioclases, but its presence sometimes chiefly in the orthoclase and quartz would indicate that in these cases it has been among the latest products of the cooling magma, forming at least after the plagioclase and augite.

*Chemical composition of the diabase.*—The range in chemical composition of the intrusive diabase is presented in the analyses of the subjoined table, in which are included for comparison analyses (XIV.–XVI.) of the corresponding intrusive sill and a thin acid dike[1] in the Connecticut Valley Triassic, and the closely similar Antarctic rock described in the footnote on page 109.

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[1] The little fine-grained dike described by E. O. Hovey (*Am. Jour. Sci.*, 4th Ser., Vol. III., 1897, pp. 287–292) is the most acidic igneous rock yet observed in the Newark formation. The thin sections showed almost a purely feldspathic rock without augite or recognizable quartz. The high soda and alumina and the low potash, lime and iron are also in striking contrast with the acid facies of the Palisade sill represented by analyses I. and XI.

*Analyses of the intrusive diabase.*

| | I. | II. | III. | IV. | V. | VI. | VII. | VIII. | IX | X. | XI. | XII. | XIII. | XIV. | XV. | XVI. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $SiO_2$ ...... ..... | 60.05 | 51.34 | 53.13 | 51.88 | 50.40 | 52.48 | 49.62 | 51.14 | 51.03 | 49.02 | 56.78 | 51.46 | 50.34 | 51.78 | 60.13 | 53.26 |
| $Al_2O_3$.. ........ | 11.88 | 12.71 | 13.75 | 14.53 | 15.60 | 14.98 | 10.51 | 12.99 | 11.92 | 10.14 | 14.33 | 13.98 | 15.23 | 14.20 | 20.47 | 15.64 |
| $Fe_2O_3$.. ........ | 3.22 | 2.65 | 1.07 | 1.35 | 3.65 | 1.13 | 0.64 | 1.50 | 1.52 | 1.54 | 5.76 | 2.66 | 2.82 | 3.59 | 1.04 | 0.24 |
| FeO ............. | 10.21 | 14.14 | 9.10 | 9.14 | 6.30 | 9.25 | 12.02 | 9.14 | 10.85 | 10.46 | 9.27 | 8.92 | 11.17 | 8.25 | 0.72 | 7.44 |
| MgO............. | 0.85 | 3.66 | 8.57 | 7.78 | 6.08 | 7.75 | 15.98 | 11.58 | 12.08 | 17.25 | 1.58 | 7.59 | 5.81 | 7.64 | 1.15 | 8.64 |
| CaO.. ........... | 4.76 | 7.44 | 9.47 | 9.98 | 10.41 | 10.83 | 7.86 | 10.08 | 9.22 | 8.29 | 5.26 | 10.49 | 9.61 | 10.70 | 2.59 | 12.08 |
| $Na_2O$........... | 4.04 | 2.43 | 2.30 | 2.06 | 2.57 | 1.87 | 1.40 | 1.72 | 1.50 | 1.59 | 3.43 | 4.75 | 2.93 | 2.14 | 9.60 | 1.25 |
| $K_2O$............. | 2.10 | 1.44 | 1.04 | 0.93 | 0.62 | 0.43 | 0.55 | 0.52 | 0.39 | 0.40 | 1.75 | | 1.02 | 0.39 | 1.06 | 0.58 |
| $H_2O+$ ......... | 0.66 | 0.69 | 0.90 | 0.97 | 1.67 | 0.23 } 41 | 0.49 | 0.59 | 0.54 | 0.59 | 0.10 | ...... | 0.07 | 0.63 | 3.44† | 0.41 |
| $H_2O-$ ......... | 0.21 | 0.18 | | 0.12 | 1.02 | 0.18 | 0.33 | 0.14 | 0.17 | 0.16 | 0.33 | ...... | 0,19 | | | 0.35 |
| $TiO_2$............ | 1.74 | 3.47 | ...... | 1.35 | 1.35 | 1.30 | 1.01 | 1.13 | 0.93 | 0.99 | 1.44 | 1.06 | 1.56 | * | tr. | 0.70 |
| $P_2O_5$............ | 0.52 | 0.20 | ...... | 0.14 | 0.16 | 0.13 | 0.16 | 0.06 | 0.08 | 0.11 | 0.36 | 0.17 | 0.20 | 0.14 | ...... | 0.04 |
| MnO............ | 0.28 | 0.36 | 0.44 | 0.10 | 0.06 | 0.27 | 0.09 | 0.16 | 0.15 | 0.16 | 0.25 | ...... | 0.14 | 0.43 | tr. | 0.11 |
| | 100.52 | 100.71 | 99.77 | 100.33 | 99.89 | 100.83 | 100.71 | 100.75 | 100.38 | 100.70 | 100.64 | 101.08 | 101.09 | 99.89 | 100.20 | 160.74 |
| Sp. Gr.......... | 2.872 | 3.089 | 2.96 | 2.98 | 2.89 | 3.110 | 3.118 | 3.051 | 3.122 | 3.152 | ...... | ...... | 2.968 | 3.03 | 2.63 | ...... |

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* Dr. Howe determined $TiO_2$ from West Rock 1.41.

† $CO_2$ and $H_2O$.

I. Quartz-diabase, Pennsylvania railroad tunnel, Homestead, about 400 feet from western portal. (Anal. No. 119; specimen and thin section No. 315L.) R. B. Gage, analyst.

II. Quartz-diabase, Jersey City, Pennsylvania railroad cut near Marion Station. Coarse-grained rock. (Anal. No. 35; specimen and thin section No. 15L.) R. B. Gage, analyst.

III. Diabase, Jersey City, railroad cut. G. W. Hawes, analyst.[1]

IV. Basaltic diabase, Weehawken, lower contact in Pennsylvania railroad tunnels. (Anal. No. 129; specimen and thin section No. 314L.) R. B. Gage, analyst.

V. Basaltic diabase, New York, Susquehanna and Western railroad tunnel, upper contact at western portal. (Anal. No. 126; specimen and thin section 85L.) R. B. Gage, analyst.

VI. Diabase, Weehawken, road to West Shore Ferry. Fine-grained rock in the midst of the olivine diabase ledge. (Anal. No. 72; specimen and thin section No. 111L.) R. B. Gage, analyst.

VII. Olivine-diabase, Weehawken, road to West Shore Ferry. Typical coarse-grained olivine diabase. (Anal. No. 34; specimen and thin section No. 101L.) R. B. Gage, analyst.

VIII. Diabase, Englewood Cliffs, below the olivine-diabase. (Anal. No. 113; specimen and thin section No. 305L.) R. B. Gage, analyst.

IX. Diabase, Englewood Cliffs. Coarse-grained rock, above the olivine-diabase. (Anal. No. 114; specimen and thin section No. 306L.) R. B. Gage, analyst.

X. Olivine-diabase, Englewood Cliffs. Typical coarse-grained olivine-diabase. (Anal. No. 115; specimen and thin section No. 307L.) R. B. Gage, analyst.

XI. Quartz-diabase (?), Rocky Hill. Old quarry near railroad station, about 420 feet from upper contact; very coarse-grained. A. H. Phillips, analyst.[2]

XII. Basaltic diabase, Rocky Hill. Fine-grained diabase, near the lower contact. A. H. Phillips, analyst.

XIII. Diabase, Rocky Hill. Coarse-grained rock from the quarry near the middle of the sheet. A. H. Phillips, analyst.

XIV. Diabase, West Rock, New Haven, Conn. G. W. Hawes, analyst.

XV. Keratophyre dike, Fair Haven, Conn. H. S. Washington, analyst.

XVI. Quartz-diabase, Kukri Hills, King Edward VII. Land (Antarctic).

In general, alumina, ferric iron and the alkalis (soda and potash) vary with the silica, while ferrous iron, lime and magnesia vary inversely. The greatest differences occur in magnesia, which ranges from 0.85 per cent. in analysis I. to 17.25 per cent. in

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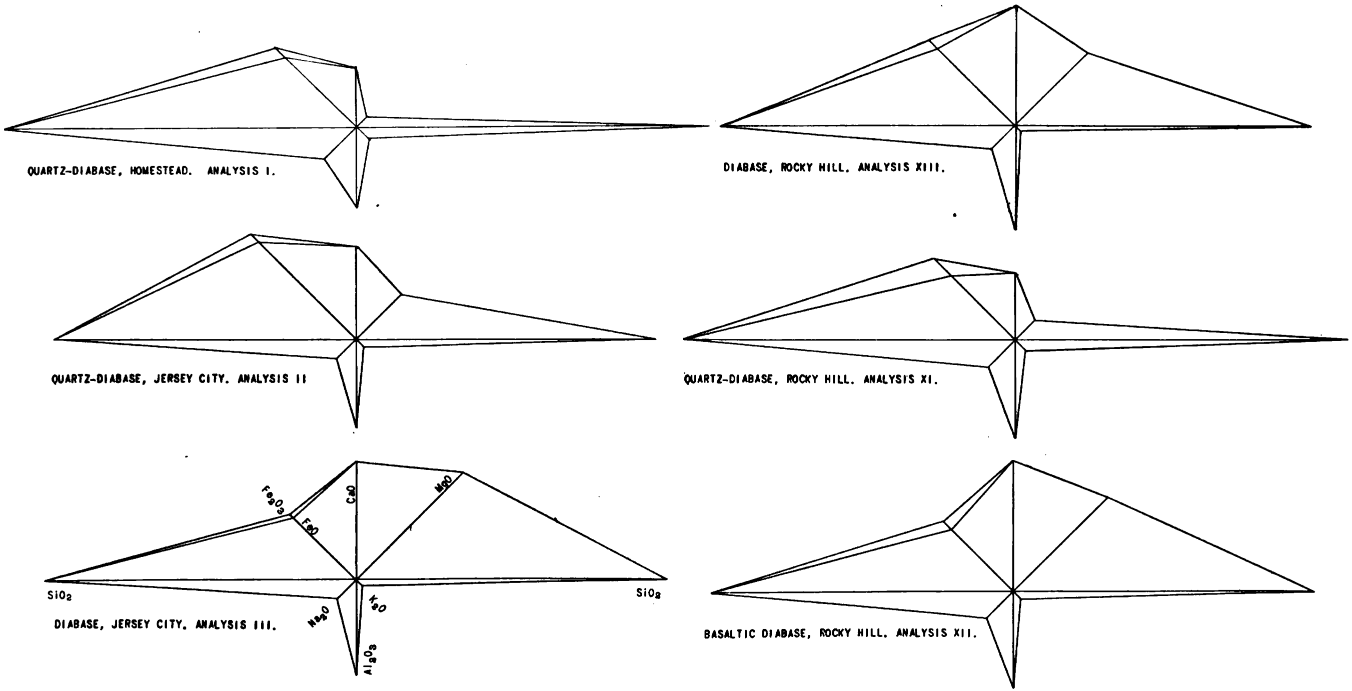
[1] "The Trap Rocks of the Connecticut Valley." G. W. Hawes, Am. Jour. Sci., IX., 1875, pp. 185–192.

[2] "The Mineralogical Structure and the Chemical Composition of the Trap of Rocky Hill, N. J.' A. H. Phillips, Am. Jour Sci., VIII., 1899, pp. 267–285.



QUARTZ-DIABASE, HOMESTEAD. ANALYSIS I.

DIABASE, ROCKY HILL. ANALYSIS XIII.

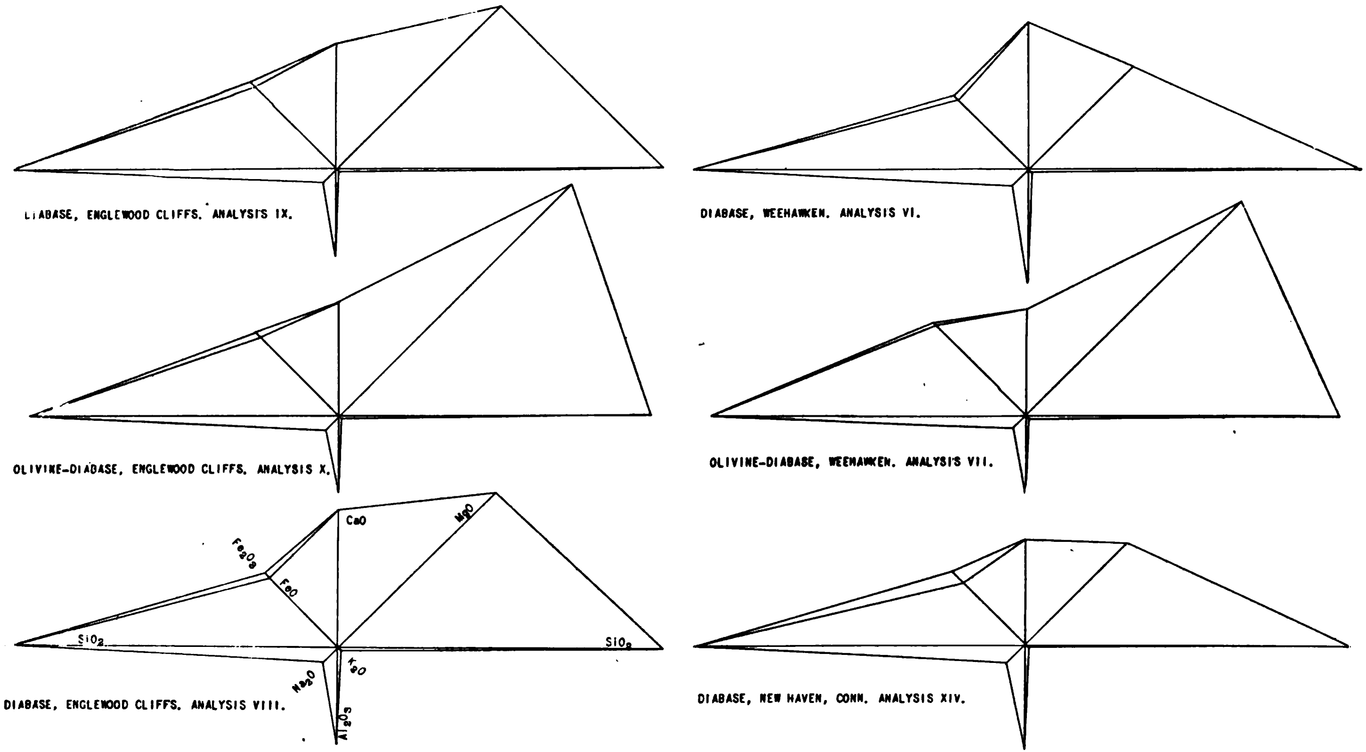
QUARTZ-DIABASE, JERSEY CITY. ANALYSIS II

QUARTZ-DIABASE, ROCKY HILL. ANALYSIS XI.

DIABASE, JERSEY CITY. ANALYSIS III.

BASALTIC DIABASE, ROCKY HILL. ANALYSIS XII.

Diagrams illustrating the composition of various facies of the diabase. (Compare Plate XVIII.)



DIABASE, ENGLEWOOD CLIFFS. ANALYSIS IX.

DIABASE, WEEHAWKEN. ANALYSIS VI.

OLIVINE-DIABASE, ENGLEWOOD CLIFFS. ANALYSIS X.

OLIVINE-DIABASE, WEEHAWKEN. ANALYSIS VII.

DIABASE, ENGLEWOOD CLIFFS. ANALYSIS VIII.

DIABASE, NEW HAVEN, CONN. ANALYSIS XIV.

Diagrams illustrating the composition of various facies of the diabase. (Compare Plate XVII.)

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analysis X. These relations are clearly expressed by the diagrams (Plates XVII., XVIII.). Chemically these rocks overlap the andesite-diorite series, on the one hand, and the most basic olivine-gabbros on the other, and the extremes are characterized by abundance of quartz and olivine, respectively.

*Mineral composition.*—The mineral constituents of the intrusive diabase, as described above, are quartz, orthoclase, plagioclase, augite, biotite, olivine, magnetite, apatite. The proportions of these minerals vary greatly with the varying chemical composition of the rock. Augite and the plagioclase feldspars usually constitute the great bulk of the rock, but all of the others, except apatite, attain rather notable abundance in certain portions. The mineral constitution of seven specimens has been determined by micrometer measurements of thin sections, with the following results:

*Mineral constitution of the intrusive diabase.*

| | I. | II. | III. | IV. | V. | VI. | VII. |
|---|---|---|---|---|---|---|---|
| Quartz | 19 | 7 | .. | .. | .. | .. | .. |
| Feldspar | 44 | 42 | 37 | 30 | 20 | 38 | 26 |
| Augite | 27 | 34 | 59 | 63 | 73 | 46 | 56 |
| Biotite | 3 | .. | .. | .. | 1 | 1 | 1 |
| Olivine | .. | .. | 1 | 5 | 4 | 13 | 16 |
| Ores | 6 | 17 | 3 | 2 | 2 | 2 | 1 |
| Apatite | 1 | .. | .. | .. | .. | .. | .. |

I. Homestead, Pennsylvania R. R. tunnels, 400 feet from west end.
II. Marion Station, Jersey City, coarse-grained rock 420 feet east of platform.
III. Englewood Cliffs, immediately below the olivine-diabase.
IV. Englewood Cliffs, immediately above the olivine-diabase.
V. Weehawken, apparently intruded into the olivine-diabase, in roadside near West Shore ferry.
VI. Weehawken, road near West Shore ferry, olivine-diabase.
VII. Englewood Cliffs, olivine-diabase.

Nos. I. and II. are typical coarse-grained quartz-diabase and gabbro, such as constitute the great bulk of the intrusive sill. The maximum quartz content probably does not greatly exceed that of No. I., the minimum drops to zero, and the average is probably below that of No. II. Nos. VI. and VII. are typical olivine-diabase, and III., IV. and V. are intimately associated with it.

Considering the diabase as a whole quartz is a far more frequent constituent of the rock than olivine, since it occurs quite generally in the coarser-grained portions that make up the bulk of the sill. It is usually found in small amount even immediately above the highly olivinic ledge and in the dike-like and irregular masses of normal diabase that penetrate it, while above this level it is almost universal. Olivine occurs somewhat sparingly in the denser contact facies, and is very abundant only in the olivine-diabase ledge, but sometimes the rock immediately above and below it is also fairly rich in this mineral.

*Classification.*—The range in mineral composition in the intrusive diabase would be designated in the older terminology by the names *quartz-diabase, diabase* and *olivine-diabase,* the prefixes quartz and olivine denoting special richness in these minerals in the most acidic and most basic portions of the rock, respectively. As already indicated, most of the coarse-grained rock, which constitutes the great bulk of the intrusive sill throughout the State, is somewhat quartzose, this mineral being quite generally present in graphic intergrowth with orthoclase, and to this extent it is not a typical diabase.

In the quantitative classification,[1] as shown in the summary below, eleven of the diabase analyses fall into Class III. (salfemane) and Order 5 (perfelic). Part of these, however, belong to Rang 3 (alkalicalcic) and Subrang 4 (dosodic), and are designated as *camptonose,* while the others go over into Rang 4 (docalcic) and Subrang 4, 5 (presodic), under the name *auvergnose.* Since these subrangs differ only in the relative amounts of alkalis and lime in the normative feldspars, the rocks are very closely similar.

Of the four remaining analyses, two belong to the much more acid Class II. (dosalane) and the other two to the more basic Class IV. (dofemane). The latter fall into a subrang as yet unnamed in the quantitive classification, and it is therefore proposed that rocks of the symbol IV.$1^2$.$1^2$.2. be designated as *palisadose,* from their typical development in the olivine-diabase ledge of the Palisades.

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[1] "Quantitative Classification of Igneous Rocks." By Cross, Iddings, Pirsson, and Washington. Chicago, 1903.

The two extremes, dacose and palisadose, as their analyses and symbols indicate, are considerably removed from each other, corresponding in chemical composition to highly quartzose and olivinic diabases, respectively, under the old nomenclature.

*Summary of Quantitative Classification.*[1]

| *Name.* | *Symbol.* | *Analyses.* |
|---|---|---|
| Dacose | II.4.2.4. | I |
| Tonalose | II.4.3.4. | XI |
| Camptonose | III.5.3.4. | II, XII, XIII |
| Auvergnose | III.5.4.4,5. | III–VI, VIII, IX, XIV, XVI |
| Palisadose | IV.$1^2$.$1^2$.2. | VII, X. |

*The olivine-diabase ledge.*—As already explained in casual references to this rock, it is the crumbling, deeply weathered rock which forms a layer 10 to 20 feet thick in the midst of the hard resistant diabase about 40 to 60 feet above the base of the Palisades (Plates XIX., XX., XXI.). It is first clearly seen at the quarry on Paterson Plank Road, Jersey City. Thence northward, it is more or less conspicuous wherever this part of the sill is exposed at least as far as Alpine, a distance of about 20 miles. Where the natural face of the rock has been removed in quarries and in road and railroad cuts, the friable, disintegrating character disappears at once, and within a few inches of the weathered surface this layer seems as hard and tough as the other parts of the sill.

The basal portions of the sill are not exposed in cliffs along Rocky Hill and Sourland Mountain, and hence, it is not known whether such a distinct layer of olivine-diabase occurs in these portions or not. By analogy one would expect to find it even with less satisfactory evidence of their physical continuity.

The boundaries of this olivine-diabase are somewhat variable. Sometimes there is a gradual transition into the normal rock above and below, while at others there seems to be quite a sharp demarcation (Plate XXI., Fig. 1). The latter is usually the case where

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[1] The highly sodic feldspathic dike from Connecticut, analysis XV., is not included here, since no similar rock has been found in the area under investigation. Dr. Hovey described it provisionally as a keratophyre, and its position in the quantitative system is indicated by the symbol I.5.2.5., which is a persodic pulaskase.

the subjacent rock is all fine grained, this layer being the first coarse texture encountered above the base. In such cases there is often an irregular interpenetration of these facies, and at times the semblance of a dike or apophysis of the finer texture, penetrating the olivine-diabase (Plate XX., Fig. 2).

Kümmel[1] suggested that this rock is probably of different mineral and chemical composition, and this is borne out by microscopic examination of thin sections (see Plate XIII., Fig. 2; Plate XVIII.; and analyses VII. and X., p. 121). It differs from the great body of the sill in the absence of the usual graphic intergrowth of quartz and orthoclase, and in the presence of abundant olivine in small, perfectly fresh crystals and rounded grains which are only about one-fourth the size of the other constituents, ranging up to a maximum of 0.3 mm. by 0.7 mm. in prismatic sections. Great numbers of these are inclosed in the feldspars, but they also occur occasionally in the augite (Plate XIII., Fig. 2). Their complete inclosure has apparently protected them from alteration, for they retain a notable freshness and clearness even in the presence of considerable decomposition of the augites. Another character of the olivine-diabase is the occasional presence of more resistant streaks and irregular areas within its mass. These, where exposed in the midst of the crumbling weathered surface, often closely resemble dikes (Plate XX., Fig. 2). Microscopic examination shows that they are sometimes normal diabase with a small amount of olivine, like the rock immediately below (and in places above also), and sometimes they are even quartz-diabase, such as forms the great bulk of the overlying mass.

The universally decomposed character of the natural outcrops of this olivine-diabase seems to be due primarily to the disruption of the inclosing feldspar by the expanding of the olivine in the first stages of its change to serpentine. The beginnings of the process are evidently of the nature of mechanical disintegration rather than decomposition, and in favorable situations considerable quantities of coarse granular debris accumulate. It is apparently only after long exposure that this passes into a fine pulverulent, clayey mass of a yellowish brown color.

*Contact facies of the diabase.*—The trap at the upper and lower

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[1] Annual Report of the State Geologist for 1897, p. 72.

Crumbling olivine-diabase ledge and talus, with solid diabase above and below. Weehawken.

Fig. 1. Olivine-diabase ledge in railway cut back of Fort Lee. The normal diabase above shows typical rectangular jointing.

Fig. 2. Olivine-diabase penetrated by normal diabase (above hammer and downward to the right). Weehawken.

Fig. 1. Upper boundary of olivine-diabase, with normal diabase above. Englewood Cliffs.

Fig. 2. Lower contact of Palisade diabase on sandstone (arkose), Pa. R. R. tunnels, Weehawken, 50 feet below mean high tide. The diabase exhibits the typical rectangular jointing. (Reproduced by courtesy of Chas. M. Jacobs, Chief Engineer.)

contacts, which are exposed in many places along the Palisades, is always exceedingly dense (aphanitic) and of a dark grayish to brownish black color. Without the microscope no crystalline structure is visible, but a distinct minute banding resembling flow-structure is sometimes seen in the thin sections. At a distance of a few feet from the contact, however, the granular character of the rock is clearly seen, but usually the individual minerals cannot be recognized within 20 to 40 feet of the contacts. Here the fine-grained rock either passes gradually into the coarse, or else it suddenly gives place to this facies at the base of the olivine-diabase ledge.

The extreme toughness of this dense contact facies is well illustrated by the difficulties encountered in the excavation of the Pennsylvania Railroad tunnels. For a horizontal distance of about 200 feet (corresponding to a thickness of about 50 feet) from the base of the sheet at Weehawken, it is said that the drills could penetrate the rock only about one-fourth or one-fifth as fast as in the normal diabase under similar conditions.

Microscopically, even the dense aphanitic contact facies of the diabase seems to be wholly crystalline, or at most to contain no more than a minute remnant of glass (Plate XVI., Figs. 1, 2). Scattered through the groundmass of slender lath-shaped feldspars in ophitic texture with granular or massive augite, are often larger well formed crystals and plates (phenocrysts) of augite and olivine, the latter often partly or wholly altered to yellowish and brownish serpentine. Biotite is also a frequent constituent, sometimes occurring in minute flakes in the ground mass, sometimes as much larger porphyritic flakes, comparable in size with the larger augites and olivines.

Frequently the olivine phenocrysts, and less commonly the augites, have been more or less rounded and etched into irregular embayed forms by corrosion, due to the dissolving action of the magma after the crystals were formed. In case of the olivines sometimes the dissolved material has recrystallized about the remaining portions in the form of a radial sheath of enstatite and biotite with grains of magnetite (Plate XVI., Fig. 2). These are further discussed under the subject of differentiation.

The blackish color of the dense contact facies seems to be in a large measure due to an abundance of minute magnetite granules throughout the rock, and these, both large and small, are often surrounded by biotite.

*Nephelite-syenite at Brookville.*—F. L. Ransome[1] has described nephelite-syenite and other syenitic and granitic rocks that occur in small scattered areas in the intrusive diabase near Brookville, on the Delaware river. From data then available the relations of these rocks were quite obscure, but Mr. Ransome concluded that, on the whole, it seemed most likely that the masses are included fragments caught up in the trap magma at the time of its intrusion. He regarded the question, however, as an open one, requiring further work with other and better exposures.

These rocks are now under investigation, and it is hoped that, with the aid of recent quarry excavations, their exact relations to the intrusive diabase may be determined.

*Dikes and apophyses.*—Numerous dikes and sheets from 1 inch to 4 feet in thickness branch off from the great sill of diabase into the shales and sandstones beneath (Plates XXII., XXIII.). These are exposed at many localities, most of which have been described by Kümmel.[2] Few upper contacts have been found accessible and at none of these have dikes been observed. There are, however, numerous dikes in the overlying strata in the vicinity of all the larger outcrops of this rock from the Hudson to the Delaware. Kümmel has traced some of these to their junction with the main sill on Sourland Mountain, and there is little doubt that all of them are thus connected in depth. The larger oval and irregular masses also, as at Granton, the Snake Hills, Griggstown and Moores on the Delaware River, are to be regarded as apophyses, connected at comparatively shallow depths with the same intrusive sill.[3]

In density and color the dikes and the contacts of the apophyses are like the contact facies of the main mass of the diabase. Under the microscope some of the thinnest dikes and sheets, those less than 6 inches in thickness, are found to contain considerable quantities of brownish glass, which is sometimes nearly black with dust-like granules of magnetite. Otherwise they consist of an ophitic ground mass of slender plagioclase feldspars and augite, sprinkled

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[1] Am. Jour. Science, Vol. VIII., 1899, pp. 417–426.

[2] Annual Report of the State Geologist for 1897, pp. 63–65, 68, 69, 92.

[3] J. Volney Lewis, Annual Report of the State Geologist for 1906, pp. 117–121.

Fig. 1. Thin intrusive sheet 1 foot below the base of the Palisade sill, Coytesville. The diabase above shows typical rectangular jointing.

Fig. 2. Intrusive sheet (*d*, *d*) branching off from the Palisade diabase (*D*) into the white underlying sandstone (arkose). Guttenburg.

Fig. 1. Base of Palisade sill (*D*) with 3 intrusive sheets (*d*, *d*, *d*) in underlying sandstone and shale. Foot of Palisades, 2 miles east of Englewood.

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Fig. 2. Dike in red shale. ⅓ mile north of Blackwell's Mill. The shale at the left has been bleached 4 or 5 feet from the contact by percolating waters.

with porphyritic crystals of olivine and augite, as in the contacts of the main sill. The coarser central masses of the apophyses consist of typical quartz-diabase, exactly like that of the main body of the sill, having a coarse ophitic to granitic texture and being characterized by the absence of olivine and the constant presence of a notable amount of quartz and orthoclase in graphic intergrowth.

*Differentiation.*—Inasmuch as the several types of rocks above described occur as continuous portions of a single intrusive sill, they must be regarded as together constituting a unit. There is no evidence that they are products to any extent whatever of separate intrusions, or even of successive pulsations of an extended period of injection. Their present constitution and relations are best understood as the results of differentiation, or separation of the constituents of the molten magma after its intrusion and during the long period required for cooling and solidification.

The thickness of the sill or intrusive sheet varies considerably in its 100 miles of outcrop in New York and New Jersey, but it is everywhere several hundred feet thick, and in places, as along the Palisades above Weehawken, and in the thicker parts of Rocky Hill and Sourland Mountain, it approximates 1,000 feet. Under cover of a great blanket of overlying shales and sandstones, probably many times its own thickness at the time of intrusion, though since partly removed by erosion, this highly-heated molten magma cooled very slowly, and probably remained in a liquid condition for a considerable period. The only exceptions to this are the immediate contacts with the inclosing strata, which must have been quickly chilled; on the other hand, the adjacent shales and sandstones themselves also became highly heated, and subsequent cooling was probably slow. The surrounding rocks are poor conductors of heat, and once a crust had formed, and the strata at the contact were well heated, the inclosed liquid mass became in a measure insulated. Under such conditions the outer crust of the magma would very slowly thicken until the whole mass became solid.

Professor Iddings' conclusion[1] that the process of differentiation which gives rise to variations in the character of different parts of such a magma "must be of a chemico-physical nature;" that is, a chemical process resulting from varying physical conditions, espe-

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[1] Bulletin Phil. Soc. Washington, Vol. XII., p. 194.

cially temperature, is doubtless true in most cases, and probably to some extent in all, but in the present state of our knowledge, it seems scarcely justifiable to exclude entirely the possibility of purely physical causes acting alone. This applies particularly to the settling of heavier crystals in the more basic magmas, which are highly fluid, and might well remain so long enough for such a process to produce considerable effect. In fact, the extent of such gravitation of the heavier minerals may be regarded as a measure of the degree and duration of liquidity after the beginning of crystallization, and the absence of such effects only as evidence that the particular magma had become too viscous to permit effective differentiation from this cause.

Further, the time of crystallization of a particular mineral is held to have some definite relation to its concentration in the solution, and this seems to imply that the definite molecular group exists as the point of saturation is approached, ready to crystallize when that point is reached. In acid magmas the proportion of basic constituents is small, and saturation would occur only at a correspondingly lower temperature than in those basaltic magmas that carry basic substances in large amounts. Hence the crystallization of magnetite and augite in rhyolite, for example, would probably not take place before the whole magma had cooled to a highly viscous condition, particularly as this condition would occur at a comparatively early stage of cooling in the more difficultly fusible siliceous solvent.

The basaltic magma, on the other hand, with its low melting point and its high content of dissolved basic constituents, would reach the point of saturation for some of these (magnetite and olivine, for instance) at comparatively high temperatures and while the lava is still quite fluid. If such minerals crystallize any considerable length of time before the other constituents, the magma remaining liquid, their concentration in the lower parts of the mass by gravitation must result as a mechanical necessity, unless there are eddies or other currents sufficiently strong to prevent; and such currents would probably prevent differentiation by any process, in the parts affected. In many rocks the ore grains are much smaller than the silicate minerals, and would therefore offer greater resistance to settling through the magma. In such cases gravitation would affect the larger olivines particularly.

In the next stage of crystallization, there would undoubtedly be the same tendency for the augite crystals to sink and the feldspars to rise toward the top of the sheet, but by this time the increasing viscosity of the magma and the clouds of new minerals forming would doubtless prevent any extensive segregation of these by gravitation.

The degree of concentration finally attained by this process would depend on the fluidity of the magma and the time intervening between the formation of the first minerals and the next succeeding stages of crystallization. Further, the position reached by such descending minerals would be determined by the viscosity of the magma toward its lower contact, that is, by the extent of cooling due to the rocks into which it was intruded.

The basic concentration forming the olivine-diabase ledge in the Palisades was not formed at the cooler contact, nor is it duplicated in the corresponding upper portions of the sill. Its formation cannot, therefore, be attributed to the action of Soret's principle or any other process of concentration due to cooling. If regarded as the result of chemical differentiation before intrusion, it must be an earlier or later injection than the accompanying diabase above and below, but its uniformly coarse texture and its great regularity in thickness and position with reference to the base of the sill would seem to preclude this hypothesis. The great overlying body of diabase, however, has been entirely freed from olivine, except at the upper contact, and this mineral has been lodged in the remarkably distinct zone of olivine-diabase, 10 to 20 feet in thickness and lying 40 to 50 feet above the base of the sill. The bulk of the diabase, however, is somewhat quartzose, but it often passes into normal diabase, and toward the contacts, into a somewhat olivinic facies, which is more basic in character, though much less so than the olivine-diabase ledge referred to above.

This relatively slight contact-differentiation may be quite reasonably attributed to the operation of Soret's principle, that is, to the concentration of the dissolved bases in the cooler parts of the solution. This process was aided perhaps by feeble convection, by which all parts of the magma were successively brought within the range of the more effective temperature differences at the contact. Thus the bases were removed to such an extent that an excess of silica finally remained to crystallize as quartz throughout the greater part of the central and upper portions of the sill.

A hypothesis of stoping or splitting off and engulfing slabs of overlying strata, afterward assimilated by solution in the magma, has been invoked instead of some process of differentiation in explanation of certain facies of eruptive rocks.[1] In case of the Palisade diabase, however, as in some cases at least to which this theory has been applied, the process would seem to be mechanically impossible on any important scale. The diabase is 20 per cent. heavier than the inclosing strata, and unless this was more than offset by expansion in the fused mass, it would be impossible for sandstone or shale to sink into it, even if completely broken away from the parent stratum. If stoping is possible at all in such cases it must be underhand stoping, which the advocates of the hypothesis have not yet claimed.

The first formed crust, chilled quickly by contact with the cold strata at the time of intrusion, is naturally of average composition, or nearly so, with some scattering but not abundant olivine. Forty to 50 feet above the base, however, the crumbling olivine-diabase ledge, 10 to 20 feet thick, is rich in olivine and contains far more augite than feldspars. Above this the great mass of the sill, hundreds of feet in thickness, is entirely free from olivine and contains a notable, though variable, amount of quartz and orthoclase in graphic intergrowth. In a general way the upper portions of this mass are notably richer in feldspars, the lighter sodic plagioclases and orthoclase preponderating, while the lower portions abound in augite and the more calcic plagioclases prevail.

There is, however, some reason for believing that differentiation by some process had made some progress before the intrusion of the sill into its present position, and that therefore even the first chilled contacts do not quite represent the original undifferentiated magma. Evidence of this is found in the rounded and sometimes badly corroded condition of the olivine crystals in the fine-grained contact facies of the rock and in the occasional development of corrosion mantles of more acid constitution about their borders. In sections (Nos. 85L and 114L) from the contact in the western

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[1] **Daly, Am. Jour. Sci., Vol. XV. (1903), p. 269; Coleman, Jour. Geol., Vol. XV., p. 759.**

Fig. 1. Vertical contact of diabase (on the right) with sandstone and shale, southeast side of Snake Hill.

Fig. 2. Vertical contact of diabase (on the left) with sandstone and shale, south end of Snake Hill.

**Fig. 1.** Vertical contact of diabase (on the right) with shale and sandstone (forming the slope to the left), west side of Snake Hill.

Fig. 2. Dike (*d*, *d*) from diabase boss, intersecting sandstone and shale, southeast side of Snake Hill.

Dikes (*d*, *d*) of diabase intersecting brown sandstone, quarry near copper mine, Arlington.

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end of the New York, Susquehanna and Western Railroad tunnel, near New Durham, the larger olivines are surrounded by a narrow border consisting of radial enstatite with irregular grains of magnetite and biotite. The smaller crystals are either wholly replaced by these minerals, or nearly so. The olivine remnants are considerably altered into serpentine, and this may account for the magnetite, but the enstatite and biotite must be the result of crystallization from a more acid magma, which was in the act of dissolving the olivine when the process was stopped by intrusion and solidification, and the olivine crystals must have formed originally in a more basic magma.

The more basic products of such deep-seated differentiation, complementary to the somewhat quartzose diabase which constitutes the bulk of the intrusive sill, as well as any possible highly siliceous or granitic facies, are entirely unknown at the surface, or if known, their relations to the igneous rocks of the Newark formation have not been recognized.

Two unusual microscopic characters, which may also be regarded as evidence of earlier differentiation, were observed in certain thin sections of the dike rocks. (1) A section (No. 62L) from near the contact in the quarry at the south end of the hill at Granton shows an unbanded feldspar in large, rounded grains, presumably orthoclase, surrounded by corrosion mantles of fine granular augite and flakes of biotite (Plate XVI., Fig. 3). Other feldspars have been entirely replaced by nest-like aggregates of these minerals, and similar aggregates, apparently of exactly the same character, were observed in the rock (No. 268L) from the east side of Round Mountain. (2) A section (No. 7L) from one of the thin sheets at Martin's Dock, on the Raritan River, below New Brunswick, shows complete replacement of olivine phenocrysts by fine granular feldspar.

## CUSHETUNK AND ROUND MOUNTAINS.

The trap masses of Cushetunk and Round mountains are quartz-diabase of exactly the same character as that of the main mass of the intrusive sill, but their connection with it is not so obvious as in the case of the other intrusive masses of the State, and the question whether they were intruded at the same time or somewhat earlier or later must remain in doubt. Whether or not these rocks contain a subordinate layer of olivine-diabase is uncertain, and the fact that their basal portions are deeply buried in debris would make it difficult if not impossible to determine. That they are undoubtedly parts of the same magma, however, and the fact that they represent the same stage of differentiation as the great bulk of the larger sill, lends probability to the hypothesis of contemporary intrusion.

## INCLUSIONS IN THE PALISADE DIABASE.

With the exception of an occasional mention of shale inclusions near the base of the sill, as in Hoboken, by Darton,[1] and at Linnwood, by Kümmel,[2] these seem largely to have escaped observation heretofore. This is particularly true of the extraordinary dike-like inclusions of arkosic sandstone described below, which constitute practically a new set of phenomena for this region.[3]

Slabs or sheets of the sedimentary strata into which the igneous rocks were injected have been frequently split off and engulfed in the molten magma in masses varying from a few inches to many feet in thickness. The first step in such a process is seen in Plate XXII., Fig. 1, where a thin sheet of the diabase has followed a bedding-plane about a foot below the base of the main sill. If any portion of the intervening sedimentary bed had broken or parted along a joint-plane and the edge had tilted up somewhat against the flow of the intruding magma, it would have been raised by the current to a more steeply inclined or even vertical position. Such sedimentary inclusions are found in the Palisades at several localities in addition to that referred to above.

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[1] Bulletin U. S. Geological Survey No. 67, 1890, p. 45.

[2] Annual Report of the State Geologist for 1907, p. 66.

[3] Ransome has described (Bulletin U. S. Geological Survey No. 303, p. 47) inclusions of tabular basalt slabs in rhyolite at Bullfrog, Nev., which are remarkably similar in their mode of occurrence to some of these in the Palisades. "Some of these are irregular. Others are thin tabular bodies which stand nearly vertical, and which, did they occur alone, might easily be mistaken for dikes. * * * That the apparent dikes are really inclusions is certain, but no satisfactory explanation has yet been found for their vertical attitude in a flow that must have had a generally horizontal movement, or for the source of the basaltic material."

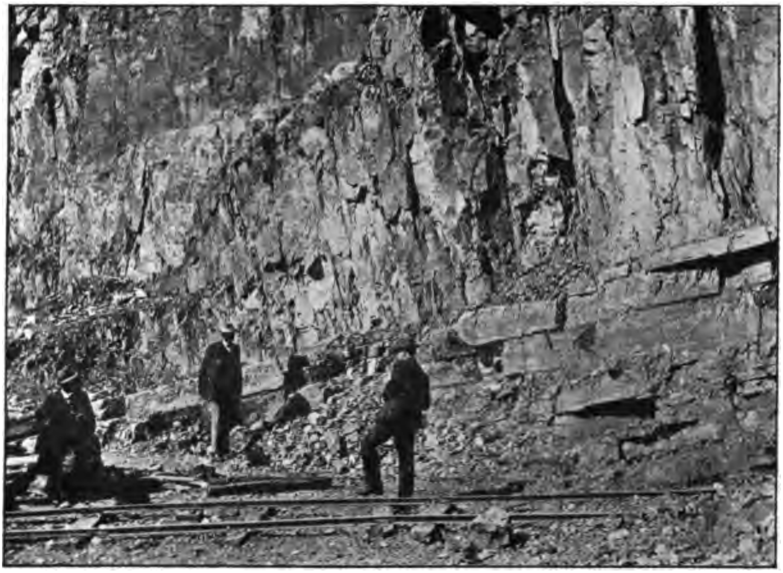

Fig. 1. Base of intrusive diabase on sandstone, quarry near Granton. (Photograph by G. E. Ashby.)

Fig. 2. Base of same diabase sheet as shown above, with detached slab of sandstone floated up into the magma. Quarry, 1 mile north of Granton.

Fig. 1. Arkose (feldspathic sandstone) inclusion in the Palisade diabase, south side Pa. R. R. cut, 420 feet east of Marion station, Jersey City.

Fig. 2. Arkose inclusion in diabase, north side of Pa. R. R. cut, 45) feet east of Marion station, Jersey City.

(1) A thin sheet of feldspathic sandstone (arkose) is tilted up into a nearly vertical position in the east end of the old quarry at Coytesville. It varies from one to two feet in thickness, and a thin layer has been partly torn away on one side (Plate XXIX., Fig. 2).

(2) At Edgewater, near Fort Lee, a bed of shales 2 feet thick and parallel to those below, is exposed in the diabase along the trolley road up the cliff, about 15 feet above the base of the sheet.

(3) In the high cliffs overlooking the road that leads up from the West Shore ferry, at Weehawken, a bed of feldspathic sandstone or arkose, about a foot thick, extends vertically from the base of the cliff to the top. Forty to 50 feet of the base of the sill are here covered with debris, however, so that the inclusion is not traceable directly to the strata below. The sandstone has a well developed diagonal lamination, apparently cross-bedding, which is distinct even in thin slivers of an inch or less that branch off into the surrounding diabase (Plate XXIX., Fig. 1).

(4) On both sides of the Pennsylvania Railroad cut, 420 feet east of Marion station, Jersey City, thin sheets of arkosic sandstone, perhaps originally continuous, lie in an irregular, undulating position in the diabase, with an average westward dip of about 20 degrees. It is most variable on the south side, where it ranges from 5 inches to 3 feet in thickness, and has a remarkable resemblance to a light colored acid dike (Plate XXVIII.).

In some of the larger offshoots of the main sill somewhat similar inclusions have also been observed.

(5) In the quarry of the Fairview Stone Crushing Company, at the north end of the diabase hill between Fairview and Granton (Plate XXVII., Fig. 2), an arkosic sandstone slab about 10 feet thick at one end and tapering to about 5 feet at the other and over 100 feet long, lies at an angle of about 10 degrees with the horizon. This inclusion is within 10 feet of the bottom of the diabase sheet, which here rests on thinly laminated black and gray shales.[1]

(6) Another vertical sheet of sandstone (arkose), 6 to 15 inches thick, stands in the direction N. 32° W. across the workhouse quarry in Belle Mountain, a small diabase knob on the Delaware river, about three-fourths of a mile above Moores.

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[1] **Kümmel described this quarry (Annual Report, 1897, p. 73), but the exposure was not sufficient at that time to determine the relations of the arkose.**

The thinner of these inclusions in all cases look remarkably like acid dikes cutting across the dark basic trap rock. This effect is intensified by their originally granitic character and by recrystallization and the development of new minerals by metamorphism. Not even in thin section under the microscope was their true character recognized at first until less altered facies were found.

*Megascopic characters.*—The thinner portions of the sandstone inclusions, enumerated above, are very hard and compact, and look in all respects like fine-grained, light colored granite with a slight sprinkling of dark constituents. From this facies every gradation is found to apparently normal feldspathic sandstone (arkose) in the thicker portions, showing little sign of alteration. This slightly metamorphosed facies is found abundantly, even in the thicker parts (3 feet) of the inclusion at Marion, and apparently constitutes most of the large mass at Granton. It is a relatively friable rock, crumbling under the blow of the hammer like the similar arkose that forms beds of considerable extent both above and below the diabase of the Palisades along the Hudson.

The shale inclusion at Edgewater, like that at Linwood, has been altered into a dense flinty hornfels of dark gray to black color, so abundantly characteristic of the contacts of these intrusives throughout the State, as described under contact metamorphism below.

*Microscopic characters.*—In thin sections (Plate XXXI., Fig. 1) the thinner portions of the sandstone inclusions, up to about 2 feet thick, are found to be composed of quartz, both orthoclase and plagioclase feldspars (in very variable proportions), and augite, in a granular aggregate much resembling granite. Plagioclase is sometimes very abundant and at others scarcely present at all. The pale green augite sometimes appears to penetrate the quartz, as though formed at its expense. In smaller amounts occur irregular grains and clusters of titanite, small crystals and granular aggregates of apatite, occasional grains of magnetite, flakes of biotite, and more rarely calcite and pyrite. The feldspars, especially orthoclase, are usually more or less clouded by kaolinization. The augite is apparently identical with that of the inclosing diabase, and often exhibits the same types of alteration to uralitic hornblende, serpentine, chlorite, &c.

Fig. 1. Vertical arkose inclusion (the dark streak near the middle) in the face of the Palisades, Weehawken. The cliff shown is over 50 feet high.

Fig. 2. Arkose inclusion, nearly vertical, in the Palisades. Old quarry at Coytesville.

*Composition of arkose inclusions.*—Analyses made of thin highly metamorphic portions of two of these inclusions from opposite sides of the State by Mr. R. B. Gage, in the survey laboratory, yielded the following results:

*Analyses of arkose inclusions in the intrusive diabase.*

| | I. | II. |
|---|---|---|
| $SiO_2$ | 74.99 | 68.53 |
| $Al_2O_3$ | 10.96 | 12.89 |
| $Fe_2O_3$ | 0.36 | 1.42 |
| FeO | 2.70 | 5.27 |
| MgO | 1.37 | 1.35 |
| CaO | 1.80 | 2.24 |
| $Na_2O$ | 4.37 | 4.90 |
| $K_2O$ | 2.21 | 0.84 |
| $H_2O+$ | 0.46 | 0.74 |
| $H_2O-$ | 0.31 | 0.30 |
| $TiO_2$ | 0.74 | 1.02 |
| $P_2O_5$ | 0.08 | n.d. |
| MnO | 0.12 | n.d. |
| | 100.47 | 99.50 |
| Sp. Gr. | 2.674 | 2.815 |

I. Arkose inclusion in Pennsylvania Railroad cut 420 feet east of Marion station, Jersey City. From south wall of the cut about 3 feet above the roadbed (Plate XXVIII., Fig. 1).

II. Arkose inclusion in the east side of the quarry in Belle Mountain, three-quarters of a mile above Moores, on the Delaware river.

The chief constituents, quartz, feldspar and augite, are in fairly uniform equant grains, and the rock in its present holocrystalline condition might be termed a *recomposed augite-granite.* The augite, however, seems to be in part at least the result of constituents derived from the inclosing magma, and to this extent, of course, the rock is not reformed in the sense of having taken again its original character. Evidence of this appears in the manner in which this mineral penetrates the quartz, and also in the numerous tufts of slender rutile needles in the adjacent trap at Marion, indicating apparently the withdrawal of ferrous iron from the titaniferous ores by the acid inclusion, leaving the titanium oxide to crystallize as rutile.

Considered as recomposed granites, however, these rocks would be designated in the quantitative system of classification by the symbols, I.3.2.4. (alsbachose) and II.4.2.5., respectively, the former being the dosodic subrang of the rang *alaskase,* and the latter the presodic subrang of the rang *dacase.*

## CONTACT METAMORPHISM OF THE INTRUSIVE DIABASE.

In the immediate vicinity of the great intrusive sill, both along the Hudson and in its westward extension across the State, and also about the larger apophyses and the intrusive masses of Cushetunk and Round mountains, the stratified rocks show abundant effects of the "baking" action of the molten magma during the prolonged stages of its cooling under deep cover. This is particularly true of the shale, which constitutes the most abundant constituent of the Newark formation in New Jersey. From the contacts, outward, through a thickness of several hundred feet, the shale has been everywhere changed into a hard flinty gray to brown and black hornfels, having the hardness of slate but lacking its splitting qualities, and the original lamination is preserved only in the banding of the colors.

Back of the Palisade ridge this hornfels is well shown in the few contacts that are known,[1] especially in the railroad cuts approaching the tunnels north of Jersey City, and the buried extension of this belt to the southwest has been found in well borings and in dredging operations in the Raritan river.[2] Again, north of Rocky Hill and Sourland Mountain, similar effects are observed, often with the added character of rounded, shot-like chlorite nodules, up to an inch in diameter, sprinkled plentifully through the rock, producing a type of spotted hornfels that has been called *spilosite,* and with slender crystals and radial clusters of tourmaline (Plate XXX.). These characters are particularly well exhibited about the old copper workings, near Griggstown, where also the gradual transition from black and dark brown or gray hornfels, through various shades of purple, to the normal brick-red color of the Brunswick shale, can be perfectly observed.

In all of these cases the effects are prominent only on the back slope of the ridge. This is due to the flat slope (the low angle of dip toward the northwest), which broadens out the metamorphic belt over the gently dipping sheet of diabase as it gradually passes to greater depths. On the under side the effects are exactly the same, apparently, but the front slopes of the ridges are much

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[1] Kümmel, Annual Report of the State Geologist for 1897, pp. 61–72.

[2] J. Volney Lewis, Annual Report of the State Geologist for 1906, pp. 117–121.

Cordierite-hornfels in which cordierite is replaced by chlorite nodules, forming the "spotted slate" (spilosite) of the slopes of Rocky Hill, Sourland and Round Mountains; *a*, *b*, *c*, *f*, from old copper mine near Griggstown; *d*, ¾ mile south of mine, chlorite nodules very small, black tourmaline crystals prominent; *e*, west side of Round Mountain, weathered surface with projecting nodules; *g*, ¼ mile south of Round Mountain, ⅓ mile east of Rowland's Mills. Three-fourths natural size.

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steeper and the width of outcrop is correspondingly narrower. At certain points along the Hudson, however, more than 100 feet of shale and sandstone are exposed under the Palisades, and in all cases the shale is strongly metamorphosed.

The feldspathic sandstone (arkose) which is quite abundant in many places along the Hudson, both above and below the diabase, seems remarkably indifferent to the influence of the igneous rock, except within a few inches of the actual contact. This is well illustrated in the sandstone inclusions described above, in which only the thin parts (less than 1 foot thick) are distinctly metamorphic, while masses only 3 feet in thickness are largely almost unaltered sediment. The same is true of this rock at the contacts, where the sandstone only a few feet away shows no visible effect of the proximity of the igneous rock, while the shale associated with it is intensely metamorphosed for hundreds of feet. Manifestly the feldspar and quartz which constitute the arkose are very stable minerals at high temperatures, while the hydrous clayey materials composing the shale are readily altered by heat and recrystallized as anhydrous silicates.

## MICROSCOPIC CHARACTERS AND VARIETIES OF HORNFELS.

The microscope shows great variety in the mineral constitution of the dense aphanitic hornfels, including many different combinations of feldspar (both orthoclase and plagioclase), biotite, augite, hornblende, tremolite, garnet, spinel, magnetite, quartz, muscovite, cordierite, scapolite, vesuvianite, sillimanite, andalusite, chlorite, calcite, analcite, titanite, tourmaline, zircon, apatite and possibly leucite. The common groupings of these minerals are described below under designations of the most prominent or characteristic constituent. It should be clearly understood, however, that these are not sharply defined types, but present various degrees of gradation from one to another. Furthermore, they do not form zones or belts in any consecutive order or other systematic relation to the intrusive rock, but alternate irregularly throughout all parts of the zone of metamorphism. It is evident, therefore, that the several types of hornfels are not the result of varying degrees of metamorphism, but are dependent only on original differences in the composition of the shales themselves.

Several facies of these rocks have been described by former observers. Thus Andreae and Osann[1] found the following types at the lower contact of the Palisades:

1. *Normal hornfels;* that is, a dense feldspar-biotite rock without quartz. This is essentially the biotite-hornfels described below.
2. A similar rock with numerous gray to reddish brown zonal *tourmaline* crystals at various angles to the lamination. Each crystal is surrounded by a clear zone, free from biotite.
3. A *quartz-feldspar* variety, considered to be a metamorphic arkose, with green shredded hornblende and occasional zircons.
4. A *lime silicate hornfels* consisting of colorless pyroxene, tremolite, garnet, vesuvianite, epidote, biotite, with some feldspar, titanite and calcite. This rock is banded by the preponderance of diopside and biotite in the lighter and darker layers, respectively.

To these J. D. Irving[2] adds the following varieties, the first three being from the lower contact and the other two from the upper contact in the New York, Susquehanna and Western Railroad tunnel:

1. A hornfels composed chiefly of *biotite* with subordinate *feldspar,* and rich in dark bottle-green *spinel.* The latter occurs in grains and crystals 0.12–0.16 millimeters in diameter, which appear megascopically as black dots, like magnetite.
2. A *lime silicate hornfels,* like No. 4 above, consisting chiefly of colorless diopside, but grading toward the normal biotite-hornfels by increase in the biotite and the feldspar. Thickly scattered through the rocks are flakes of brown *basaltic hornblende,* ranging from minute specks to 3 millimeters in diameter. These are surrounded and seemingly more or less replaced by irregular scales of biotite. The rock also contains augite, sillimanite and apatite.
3. A *biotite-hornfels* with layers and lenticular masses ("augen") of a brownish *green hornblende,* with much chlorite and some feldspar.
4. Hornfels rich in imperfect crystals of the chiastolite variety of *andalusite,* varying from 1 to 4 millimeters long and one-third as broad.

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[1] A. Andreae and A. Osann: Tiefencontacte an den intrusiven Diabasen von New Jersey. Verhandlungen des Naturhist.-Med. Ver. zu Heidelberg. N. F. V. 1.

[2] School of Mines Quarterly, XX., 1899, pp. 213–223.

5. *Arkose-hornfels* containing the same.

Numbers 4 and 5 grade into each other. About the andalusite crystals there is a clear rim in the thin section, the main body of the rock being dark with magnetite and biotite. Inside of this clear rim and immediately about the crystals, however, there is a chain of large magnetite grains arranged like a necklace. The andalusite seems to occur as abundantly in the feldspathic facies of the rock as in the darker portions, although the crystals are of somewhat smaller size.

In addition to these Irving also describes a rock from the lower contact which is largely composed of minute rounded crystals, apparently leucite, although the identification was not entirely conclusive.

In the further descriptions that are added here no attempt has been made to find every contact-product. Representative specimens were collected in order to determine something of the nature and extent of the metamorphism, and it happened that most of these were distinctly different from those that had been described before.

*Biotite-hornfels.*—Several sections from the cut west of the New York, Susquehanna and Western Railroad tunnel and from the north slopes of Rocky Hill show a dense aggregate of biotite flakes and minute grains of feldspar with scattering magnetite and occasional quartz-bearing layers, the latter usually coarser grained. Frequent alternating bands of lighter and darker colors are due to the varying proportions of biotite to feldspar developed in alternate laminæ of the shale. Chlorite is often present in minute flakes, and with increasing proportions it forms a transition to the chlorite-hornfels described below. Veinlets of quartz sometimes intersect the lamination.

*Chlorite-hornfels.*—This is similar to the facies just described, except that chlorite takes the place of biotite, and in the transition stages occurs in varying proportions with this mineral. Sections of this variety from the old copper mine at Griggstown show numerous grains and crystals of titanite and are occasionally traversed by veinlets of feldspar and radial fibrous hornblende.

*Augite-hornfels.*—Sections from various points in the cut west of the New York, Susquehanna and Western Railroad tunnel show a dense augite-feldspar aggregate thickly sprinkled with granules of magnetite. Occasional grains of the augite are considerably larger. Augite and magnetite are often concentrated along dark bands and

# EXPLANATION OF PLATE XXXI.

*Photomicrographs of thin sections.*

Fig. 1. METAMORPHIC ARKOSE (FELDSPATHIC SANDSTONE), *Jersey City.* Magnified 60 diameters. From the dike-like inclusion shown in Plate XXVIII., Fig. 1. A granitic aggregate of quartz, feldspar (both orthoclase and plagioclase), and secondary augite. The feldspars are crowded with alteration products. Thin section No. 297–L.

Fig. 2. DENSE METAMORPHIC ARKOSE, OR ARKOSIC HORNFELS, *old quarry under the Palisades, 2 miles east of Englewood,* 3 feet below the base of the main sheet of diabase. Photographed with crossed nicols; magnified 50 diameters. Shows several cordierite crystals; a pseudo-hexagonal trilling appears to the left. Thin section No. 90–L.

Fig. 3. ALTERED CORDIERITE-HORNFELS, OR "SPOTTED SLATE," *Ten-Mile Run, 2 miles northeast of Griggstown.* Magnified 18 diameters. Shows hexagonal and rounded chlorite pseudomorphs of cordierite. Thin section No. 277–L.

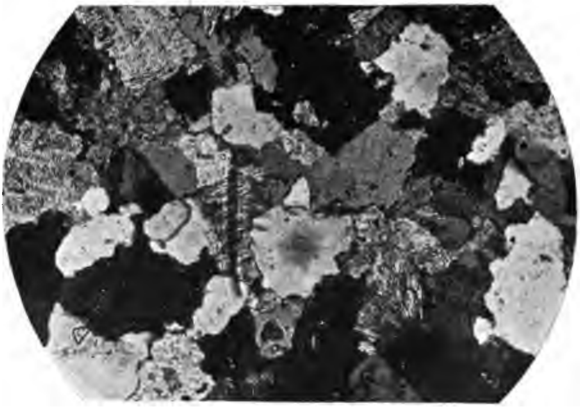

Fig. 1.

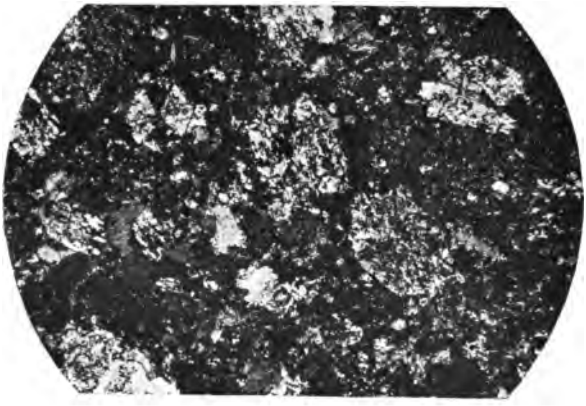

Fig. 2.

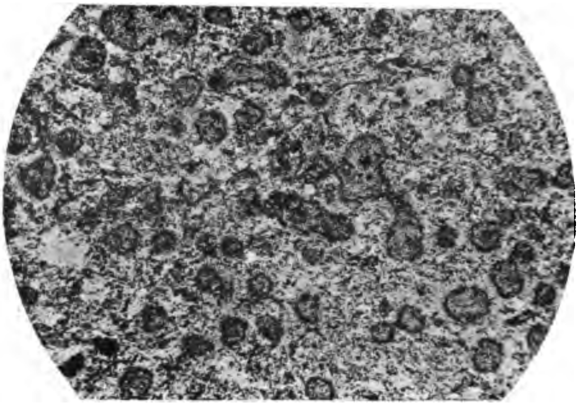

Fig. 3.

irregular splotches, giving rise to corresponding variations in the color of the rock.

*Augite-biotite-hornfels.*—Several sections from near the under contacts in the eastern portal of the West Shore Railroad tunnel and the head of Fourteenth street, Hoboken, show dense augite-feldspar aggregates alternating with darker bands and splotches of augite, biotite and feldspar. Larger ragged areas of augite and biotite occasionally occur and these minerals are sometimes thickly sprinkled (poikilitic) with inclusions of the other constituents. The biotite is pleochroic, pale yellow to dark reddish brown, and often nearly opaque. The pale green augite is sometimes partly altered to chlorite, sometimes to yellow serpentine, and the larger grains are frequently grouped in radiating rosettes. Magnetite occurs in scattering grains and occasional veinlets are filled with augite and chlorite.

*Cordierite-hornfels* (*spilosite*).—This type occurs at numerous localities both above and below the great intrusive sill along the Palisades, and spilosite, in which the muscovite and chlorite nodules are apparently pseudomorphs after cordierite, is abundant along Rocky Hill and Pennington and Sourland mountains. Cordierite hornfels consists of a dense groundmass of feldspar and biotite or chlorite (or both) abundantly sprinkled with rectangular, hexagonal, rounded and irregular sections of cordierite. Occasional larger biotite and feldspar grains occur and some magnetite with rarely shreds of muscovite. On the other hand, biotite sometimes entirely disappears from the groundmass. Cordierite is found in all stages of development from perfectly-formed crystals and pseudo-hexagonal trillings to roundish, ill-defined clearer patches in the dense groundmass, with indistinct radial extinction (Plate XXXI.). It also exhibits all stages of alteration to confused scaly aggregates of hornblende, muscovite (pinite), biotite or chlorite, and sometimes feldspar and calcite (Plate XXXII.). Granules of magnetite are usually abundant in all cases. The cordierite crystals are often of minute microscopic size, but the chlorite and muscovite pseudomorphs at Griggstown Mine, which probably represent original cordierite, sometimes attain a diameter of about 25 millimeters (1 inch), although usually less than one-fourth that size. Biotite and magnetite are frequently more abundant in the hornfels immediately about the cordierite crystals, although the latter are sometimes surrounded by narrow interven-

# EXPLANATION OF PLATE XXXII.

*Photomicrographs of thin sections.*

Fig. 1. ALTERED CORDIERITE-HORNFELS (SPILOSITE, OR "SPOTTED SLATE"), *old copper mine, 1 mile south of Griggstown.* Magnified 10 diameters. Shows a large hexagonal cordierite replaced by a mass of chlorite and magnetite granules. Thin section No. 275–L.

Fig. 2. ALTERED CORDIERITE-HORNFELS, *same locality as Fig. 1.* Magnified 10 diameters. Rectangular pseudomorph of chlorite after cordierite. Thin section No. 287–L.

Fig. 3. ALTERED CORDIERITE-HORNFELS, *same section as Fig. 2.* Magnified 10 diameters. A hexagonal chlorite pseudomorph after cordierite.

Fig. 4. CORDIERITE-HORNFELS, *west end of N. Y., S. & W. R. R. tunnel, near Fairview;* 130 feet west of the upper contact of the Palisade diabase. Magnified 10 diameters. Shows cordierite crystals largely altered to mixtures of muscovite, biotite and magnetite, though still retaining unaltered remnants of the original mineral. Thin section No. 78–L.

Fig. 5. ALTERED CORDIERITE-HORNFELS, *same section as Fig. 1.* Magnified 10 diameters. Shows a pseudo-hexagonal chalcocite crystal and connecting veinlet of the same mineral.

Fig. 6. SCAPOLITE-HORNFELS, *Byram.* Magnified 10 diameters. Shows a groundmass of fine-grained feldspar, elongated flakes of biotite and rounded granules of hornblende and augite, surrounding a large central area of scapolite. Small transparent crystals of apatite are present, but do not show in the figure. Thin section No. 313–L.

PLATE XXXII.

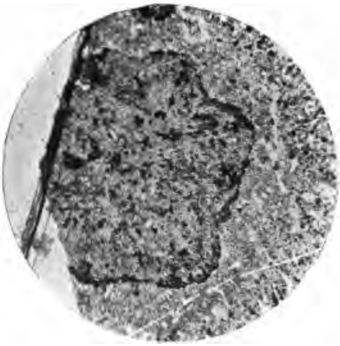

Fig. 1.

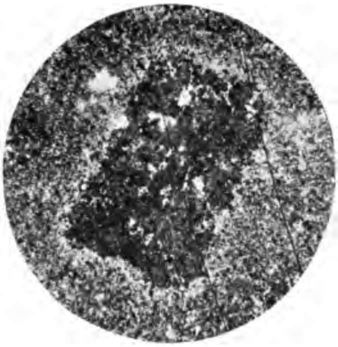

Fig. 2.

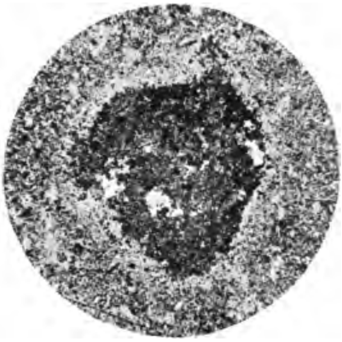

Fig. 3.

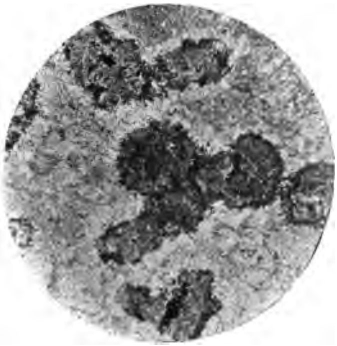

Fig. 4.

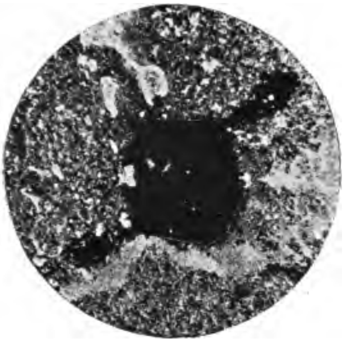

Fig. 5.

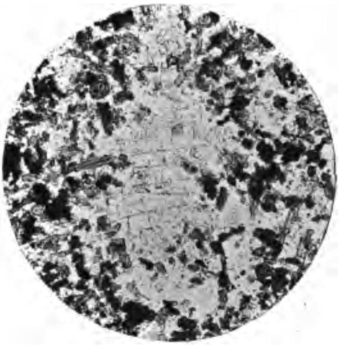

Fig. 6.

ing clear spaces. The segments of the pseudo-hexagonal trillings are also sometimes outlined by magnetite granules. Chalcocite crystals occur in some of the chlorite pseudomorphs of cordierite and other parts of the hornfels (spilosite) at the Griggstown copper mine (Plate XXXII., Fig. 5). Tourmaline (pleochroic, yellow to dark brown) is also sometimes abundant in the rock of this locality (Plate XXX.), and microscopic crystals frequently cluster about or penetrate the chlorite pseudomorphs.

The dense *cordierite-arkose,* described below, might, with equal propriety, be included here as a feldspathic *cordierite-hornfels.*

*Scapolite-hornfels.*—Sections from the lower contact at the east end of the West Shore Railroad tunnel and at Byram, on the Delaware, show large irregular areas of scapolite in a dense groundmass of feldspar, biotite, hornblende and augite (Plate XXXII., Fig. 6). The feldspar, chiefly orthoclase, is the most abundant constituent and often contains inclusions of apatite in slender needles. Biotite, the next in amount, is pleochroic, pale yellow to dark brown. Hornblende, which is nearly as abundant as biotite, occurs in rounded grains with a pale-yellow to dark-green pleochroism and often has a reddish-brown central core. Pale green augite varies from occasional scattering grains to considerable abundance. Oval areas of much finer texture in the sections are composed of the same minerals. The scapolite forms numerous large irregular areas, which are often elongated parallel to the cleavage. In some sections biotite is present in both large and small flakes, partly altered to chlorite sometimes, and magnetite grains are usually numerous.

*Vesuvianite-hornfels.*—In the cut approaching the western portal of the New York, Susquehanna and Western Railroad tunnel, 400 feet west of the contact, a laminated feldspar-augite-hornfels occurs, with darker and lighter layers according as one or the other constituent preponderates. The augite varies from minute grains to clusters and individual crystals of much larger size in irregular spots and bands. In the midst of the other constituents, vesuvianite forms large irregular areas of parallel columnar structure and incloses biotite, augite and magnetite. Analcite also forms irregular patches with rectangular cleavage, and occasional grains of epidote and calcite occur.

*Calcareous hornfels-breccia.*—A mile and three-fourths south of Lebanon, a blackish brecciated hornfels, which occurs near the diabase of Cushetunk Mountain, is composed largely of calcite and chlorite with smaller amounts of biotite and plagioclase feldspar. The whole is thickly set with minute dull black grains and aggregates that appear to be carbon.

### MICROSCOPIC CHARACTERS AND VARIETIES OF METAMORPHIC ARKOSE.

Some extremely metamorphic facies of arkose were described above under the head of inclusions, and it was pointed out in that connection that visible effects in rocks of this character are confined to the immediate vicinity of the contacts. This is true also of the contacts above and below the trap, and even microscopic effects are scarcely noticeable at a distance of a few feet. Besides the feldspars, orthoclase and the plagioclases, which in varying proportions, and with or without quartz, form the essential constituents of the unchanged rock, the microscope reveals in the metamorphic arkose varying quantities of the following minerals: Augite, biotite, epidote, cordierite, chlorite, calcite, tourmaline and apatite.

As in the case of the hornfels, described above, the usual groupings of these minerals are made the basis of several varieties, which are described here under names that indicate the prevailing or characteristic constituents.

*Augite-arkose.*—At Homestead, 80 feet south of Hose Company No. 3, a patch of arkose is firmly welded to the surface of the diabase, a small remnant of the overlying strata that have been otherwise removed by erosion. Among the much kaolinized feldspars are numerous short prismatic augites with some biotite, magnetite and minute crystals of apatite. In some parts large augites and biotites are developed, some of which inclose numerous grains of the other constituents. The rock is made up of light and dark bands in which the feldspars and the augite, respectively, preponderate. Augite and biotite often show considerable alteration to chlorite, and veinlets of feldspar (chiefly orthoclase) and augite sometimes traverse the rock.

*Epidote-chlorite-arkose.*—At the old Brown & Fleming quarry under the cliffs of the Palisades due east of Englewood, the arkose

6 inches below a 2-foot diabase sheet that branches off from the main sill, is a much kaolinized quartzose rock, with considerable secondary epidote and chlorite. Another section from the contact at the west end of the New York, Susquehanna and Western Railroad tunnel bears epidote, chlorite and calcite, and 10 feet horizontally west of the contact another layer has the same constituents. Forty feet farther west the microscope shows occasional remnants of augite altering to chlorite, and this may be considered as the probable source of much of the chlorite in these rocks. Occasional crystals of pyrite also occur.

*Tourmaline-arkose.*—In the cliffs of the old Brown & Fleming quarry, and within 6 inches below the 2-foot diabase sheet referred to above, the quartzose arkose contains frequent thick crystals of tourmaline, besides biotite and clusters of granular epidote. The original feldspars are chiefly orthoclase. It is quite possible that this tourmaline has come from the original granitic source of the arkose, and further microscopic study of the unmetamorphic rock would be necessary in order to determine this question.

*Cordierite-arkose.*—Three feet below the 2-foot diabase sheet in the old Brown & Fleming quarry above referred to, an 18-inch bed of gray sandy shale is penetrated by two 6-inch diabase sheets. A section from this bed shows it to be essentially a fine-grained orthoclase-arkose, considerably kaolinized and thickly set with cordierite in rectangular sections and pseudo-hexagonal trillings. The mineral is largely altered to confused aggregates of muscovite (pinite) and granules of magnetite, but some pale yellow to colorless crystals and numerous remnants of the unaltered cordierite still remain (Plate XXXI., Fig. 2).

This rock might, with equal propriety, be called an arkosic hornfels.

### EXTRUSIVE ROCKS.

The extrusive igneous rocks (basalts) are the finer grained and usually darker rocks that solidified from surface flows of lava. Such lava was repeatedly spread over the surface (probably a land surface) of the accumulating Newark sediments, and was in turn buried by later sediments. The appearance of these ancient lavas at the present surface is due to the subsequent tilting of the whole series toward the northwest whereby the strata and the included lava sheets have been exposed to vigorous erosion and thus beveled off and their edges laid bare (see sections on Plate X.). The more enduring basalt sheets, in the same manner as the great intrusive diabase sill of the Palisades, Rocky Hill and Sourland Mountain, persist above the general level as low ridges (mountains they are called in the Watchungs) which stretch northward from Somerville and Bound Brook almost to the New York State line (map, Plate X.). Smaller masses form low ridges and knobs about New Germantown, Sand Brook and Flemington.

### THE BASALT FLOWS.

*Definition.*—Basalt is a volcanic or extrusive rock, formed by the outflow of the lava over the surface, in contrast with the intrusive diabase, which has essentially the same chemical composition and was formed from a closely similar magma. The rapid cooling of the exposed basalt sheets produced a much denser rock, the texture being compact (aphanitic) to fine granular, and sometimes part of the lava has solidified without crystallizing, forming glass intermingled with the minute crystals. There are often larger visible crystals (phenocrysts), however, sprinkled through the dense groundmass, producing a porphyritic texture similar to that of the contact facies of the diabase. The phenocrysts are usually augite, but some of them are also feldspars, and the microscope reveals the same minerals as the chief constituents of the groundmass, with small variable proportions of magnetite and occasionally olivine, and often more or less glass, especially near the upper and lower surfaces of the various flows.

*Structure.*—The Watchung sheets vary in thickness from less than 300 feet in parts of the Long Hill (Third Mountain) flow to a maximum of about 1,200 feet in the thickest parts of the double flow of Second Mountain. It has been shown[1] that there are probably two sheets here separated by a thin stratum of shales; and hence the thickest undivided sheet would be the upper or second flow of Second Mountain, which attains a maximum of approximately 800 feet in the region just north of Bound Brook.

A horizontal sheeting or platy jointing, comparable to that of

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[1] **J. Volney Lewis, Annual Report of the State Geologist for 1906, pp. 110–115.**

Vertical joints in the basalt of First Mountain at Great Falls, Paterson. Columnar jointing also appears near the water to the right and left of the gorge.

Columnar and plane jointing in the basalt of First Mountain, North Plainfield.

Curved radial columnar jointing above, with platy lamination and irregular joints below, First Mountain basalt, Eagle Rock.

Sandstone at the base, overlain by basalt showing horizontal lamination near the contact, with large columns above and small columns at the top. Below Great Falls, Paterson

Fig. 1. Ball-and-socket joints in large columns of basalt, O'Rourke's quarry, West Orange. (Hammer, 1 foot long.)

Fig. 2. Sphenoidal, or wedge-shaped, jointing in large columns. Same locality.

Fig. 1. Spherical jointing in basalt of Second Mountain. Quarry, 2½ miles south of Stirling

Fig. 2. Irregular jointing in basalt of Second Mountain. Quarry, 1 mile south of West Summit.

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the intrusive diabase is distinctly developed in all of the basalt sheets, most prominently near their upper and lower surfaces (Plates XXXV., XXXVI.). The layers are usually thinnest near the bottom, where they are sometimes only 1 or 2 feet thick, but the structure quickly disappears in passing upward into the central massive portions of the sheets.

Jointing and faulting in these rocks are also very similar to those of the intrusives, which may be said to characterize the Newark region as a whole (Plate XXXIII.). Both joints and faults are prevailingly north-south or within 15 degrees of this direction, and approximately at right angles to the upper and lower surfaces of the sheets. Occasionally well-developed jointing is observed in the directions about N. 40° E. and N. 70° E. Joints at right angles to the prevailing direction are sometimes quite prominent, but they are usually much less numerous and often lacking altogether. More or less irregular jointing is usually present, and this increases to such an extent in some localities as to break the rock into small wedge-shaped pieces that readily fall apart in quarrying (Plate XXXVIII., Fig. 2). Many of the north-south joints have developed into faults and carry from an inch or so to more than a foot of crushed and slickensided material. Faults in other directions are much less common.

Columnar jointing (Plates XXXIV.-XXXIX.) is beautifully exhibited in many parts of the Watchung basalt sheets, and particularly well shown near Orange where exposed by extensive quarry excavations along the escarpment of First Mountain. In such cases the basalt is broken into more or less regular polygonal columns, often six-sided, in addition to the continuous joint-planes which intersect it. In many places where only regular joints appear in quarries, the shock of blasting in the quarries and the effects of weathering on exposed ledges bring out the columnar structure distinctly. Other portions of the sheets, however, seem to be entirely free from such structure. The most satisfactory explanation of its cause is that which attributes it to shrinkage-cracks formed while cooling, such cracks developing and extending themselves downward and upward from the cooling surfaces of the lava.[1] The larger columns below are due to the slower rate of cooling and the fewer cracks developed, as compared with the upper surface, which was exposed to the air. It is difficult to understand,

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[1] Iddings, Am. Jour. Sci., 3d Ser., Vol. 31, p. 321.

however, why such structure should not have been produced uniformly in sheets which are of uniform composition and approximately the same thickness over wide areas, and are presumed to have solidified under the same conditions in all parts.

*Composite character of the trap sheets.*—A horizontal structure on a much larger scale than the platy jointing described above is also observed in the Watchung basalt sheets. It is characterized by variations in color and other physical characters and also in chemical composition and seems to correspond to successive flows of lava or to successive pulsations of an irregular eruption.

In First Mountain the basal division is bluish gray in color. It is usually more or less sheeted near the base, while the upper, more massive portions are intersected by parallel vertical joints with sometimes a set at right angles, many feet apart, or are sometimes broken into large polygonal columns 2 to 4 feet in diameter at right angles to the base (Plate XXXVI.). The thickness of this portion is variable, though usually less than 50 feet. It is quite distinctly marked northward as far as Paterson and southward to Scotch Plains, and a ropy, vesicular upper surface sometimes separates it from the next overlying division.

The middle and most important division of the First Mountain sheet is a dark gray to black rock with usually a well developed columnar structure. The columns vary between 6 and 12 inches in diameter, and are often grouped in clusters radiating downward (Plate XXXV.). In many quarries where only a parallel vertical jointing is prominent in the fresh rock of this division, the effects of weathering about the borders of the quarry and the shock of blasting will often disclose the columnar structure. The characters of this division persist through the greater part of the First Mountain trap and in many places pass into vesicular and ropy structure which separates it from the next overlying division (Plate XLII.).

A third and uppermost division is found in quarries near Springfield and in the northern part of the city of Paterson, having an exposed thickness of 35 feet at the former locality and 10 feet at the latter. In both localities, however, this division constitutes the surface, and has been subjected to erosion to an unknown extent. It is a fine-grained grayish stone, and in the thicker exposure the upper part is highly vesicular.

Fault in columnar basalt of First Mountain. Old quarry at Eagle Rock.

Fault in basalt of First Mountain, Bradford Avenue, Upper Montclair. Irregular columnar jointing appears to the right. (Hammer, 1 foot long.)

Fig. 1. Undulating contact (decomposed) of two successive flows (?) of basalt. First Mountain, Bradford Avenue, Upper Montclair.

Fig. 2. Another portion of the contact shown above.

In Second Mountain there are few large quarry excavations, such as abound along the front of the more accessible First Mountain, and there is correspondingly less opportunity to observe the relations. The writer has previously shown, however, that the double crest of Second Mountain in its broad curved southern portion is probably due to two extensive flows of lava, with an intervening period during which the warping of the Passaic Basin, or Watchung, syncline was feebly begun, with the consequent concentration of sediments in the trough of the depression. This period was probably short so that only a very thin body of sediments was formed, and over these the next lava flow spread, resting over large parts of the area on the naked surface of the preceding flow.[1] Darton[2] also observed evidence of the compound character of the Second Mountain sheet at Bernardsville, Little Falls and Pompton Lake, where massive rock of slightly different characters is separated by an undulating vesicular surface. At the last-named locality there seems to be evidence also of a third thinner flow overlying the others.

In Third Mountain the quarry near Millington exposes 50 to 60 feet of the basalt in which an eroded upper gray layer 10 to 20 feet thick is separated from the nearly black rock beneath by an undulating surface that is well marked by rusty ferruginous products of alteration. In the bottom of the quarry gray rock again appears, separated from the black by one of the numerous horizontal division-planes that give a bedded or stratified appearance to the rock. At Pompton there is a distinct development of a double crest on both sides of the notch cut by the Ramapo river, and an exposure by the roadside shows soft decomposed material separating the two corresponding bodies of solid basalt.

*Surface characters of the basalts.*—Characters due to the extrusion of the lava at the surface and to its flow as a viscous liquid over large areas are found in the vesicular structure (Plate XLII.), the ropy flow-structure (the *pa-hoe-hoe* of the Hawaiian lavas) (Plate XLIII.), and in the occasional formation of volcanic tuff and breccia (Plate XLIV.).

Small bubble-cavities ranging in size up to about one-fourth inch in diameter are found frequently scattered through the

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[1] J. Volney Lewis, Annual Report of the State Geologist for 1906, p. 113.

[2] N. H. Darton, U. S. Geological Survey Bulletin No. 67, p. 24.

upper portions of all the extrusive sheets and of their several divisions that appear to mark successive flows or pulsations, sometimes in such numbers as thoroughly to honeycomb the rock to a depth of 10 feet or more. Such cavities are due to the rise of steam bubbles toward the surface of the viscous lava, but portions of the vesicular rock are often observed also at the base of the sheets and sometimes in the midst of the massive rock, apparently having been rolled under by continued flow after the frothy surface had solidified. Most of the cavities in this vesicular lava have been filled with secondary calcite, serpentine or zeolites, forming an amygdaloid. Where exposed to weathering such rock is highly permeable by water and rapidly decays to a soft rusty yellowish mass.

Pa-hoe-hoe, or the ropy rolling surfaces produced by the flowing of the viscous lava has been described by Kümmel[1] from many localities in the Watchung Mountains. It is often well preserved in natural exposures, especially in the southwestern part of the city of Paterson, and in the fresher exposures in the quarries, the rounded billowy forms are covered with dark glass one-half inch to one inch thick. Often these ropy, glassy surfaces are also vesicular or amygdaloidal. In some of the quarries such rounded forms are superimposed to a depth of 50 to 75 feet (Plate XLIII.), and the cavernous spaces between have been partially filled with calcite and quartz, the latter often amethystine, and the beautifully crystallized zeolites for which this locality has long been famous. The waters that formed these minerals by leaching their constituents from the inclosing trap and depositing them as crystals in the cavities, have also converted much of the glass into a dark green chloritic material (diabantite?).

*Breccia and tuff.*—Beneath the Second Mountain diabase at Little Falls a mass of angular and rounded blocks interspersed with finer material constitutes a thickness of 20 to 30 feet immediately overlying the sandstone in an old quarry near the pump station (Plate XLIV.).

More or less breaking of the outer crust of the lava would naturally result from the continued creep of the viscous interior after the outer parts had solidified, and at the front of the advancing sheet such fragments would be gradually rolled downward to

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[1] Annual Report of the State Geologist for 1897.

Vesicular basalt (at top of cliffs) separating two successive flows. First Mountain, North Plainfield.

Rolling flow structure (pa-hoe-hoe) in First Mountain basalt, West Paterson.

Basalt breccia (or tuff?) in contact with underlying sandstone, Little Falls.

the bottom. No great thickness of such material could accumulate in this way, however, and it is possible that we have here the products of local explosive eruption, afterward covered and more or less penetrated by a liquid flow, as suggested by Darton.[1] The absence of such material, however, from the greater part of the contact, which is here exposed for several hundred feet, is unfavorable to this hypothesis. It seems more probable that the lava here encountered a small local body of water, such as a stream or shallow pond, in the broad belt of continental sedimentation[2] over which the eruption spread; the waters suddenly chilled and shattered the mass into angular glassy fragments and these were later invaded and covered by the advancing flow.

A tuff consisting of small particles of volcanic glass, which show under the microscope inclusions of feldspar and augite crystals with occasionally pseudomorphs after olivine, was found on the dump from the tunnel of the Jersey City pipe line through Hook Mountain (a part of the Third Watchung Mountain) 1¼ miles north of Pine Brook and 5 miles southwest of Mountain View. The interstices between the glass fragments are filled with colorless to brownish radial natrolite (Plate XLVIII., Fig. 4). Numerous masses of this material were seen, but no adequate estimate could be made as to the thickness encountered, and nothing is known of its position in the section through the mountain.

*Megascopic characters.*—The extrusive rocks are all of very fine texture, varying from dense flinty-looking (aphanitic) and occasionally glassy, to fine granular texture in which the glistening cleavage planes of the minerals are distinct and sometimes the individual grains of lighter feldspars and darker augite. In all variations of texture larger visible crystals (phenocrysts) of augite, and sometimes of feldspar, are not uncommon. Augite, the most abundant constituent, is dark green to greenish black in mass and the feldspar is usually of a neutral grayish tint and more or less translucent; hence the rock itself is invariably of dark color, varying from dark greenish gray to brownish black and almost black. Some of the more altered portions, especially in much faulted and sheared areas, are brighter green to greenish black from the development of large amounts of secondary chlorite.

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[1] N. H. Darton, Bull. U. S. Geological Survey No. 67, p. 32.

[2] On the continental origin of these rocks, see J. Volney Lewis, Annual Report of the State Geologist for 1906, p. 106.

# EXPLANATION OF PLATE XLV.

*Photomicrographs of thin sections.*

Fig. 1. BASALT GLASS, *West Paterson.* Magnified 60 diameters. Scattering crystals of olivine, augite and feldspar appear in the field, besides numerous dark greenish globulitic bodies. Thin section No. 291–L.

Fig. 2. BASALT GLASS, *same locality.* Magnified 125 diameters. Shows scattering crystals of feldspar in large areas of dark spherulitic groundmass. The spherulitic structure has been largely lost in reproduction. Thin section No. 146–L.

Fig. 3. GLASSY BASALT, *Great Notch, quarry 3/8 of a mile south of the station.* Magnified 40 diameters. Shows slender and curved interlacing feldspars and granular augite set in a groundmass of dark glass. Lighter colored patches in the glass are altered to a greenish yellow serpentine-like substance. Thin section No. 170–L.

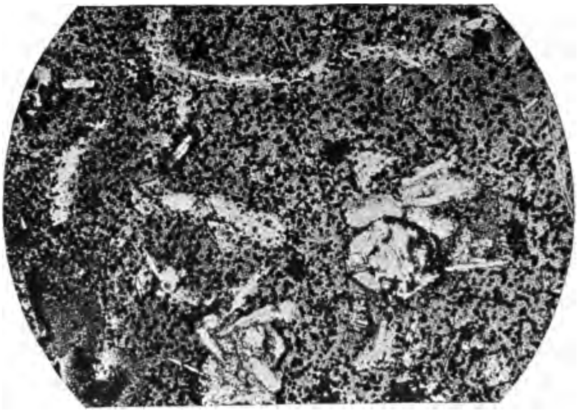

Fig. 1.

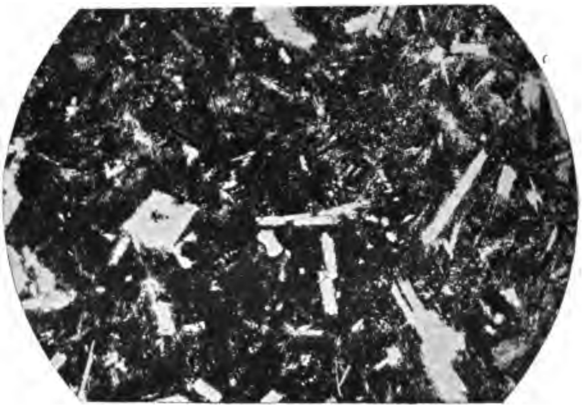

Fig. 2.

Fig. 3.

Weathered surfaces assume various tints of brown and yellow as the iron of the dark silicates is converted into the hydroxide (limonite), and soil resulting from the decay of the basalt, when not well supplied with vegetable matter, is generally quite yellowish.

*Microscopic characters.*—In thin section augite and plagioclase feldspar are found to be the chief constituents, with small amounts of magnetite and sometimes of olivine, and often considerable amounts of glass. The feldspars vary from short, stout, rectangular forms to slender, lath-shaped crystals, and the augite from granular aggregates to broad, irregular areas. Slender feldspar laths with granular augite filling the interstices gives a *diabasic* texture, while large augites inclosing numerous feldspar crystals produces the typical *ophitic* texture (Plate XLVI.).

Augite in granular aggregates preponderates in the normal basalt and, with magnetite and usually more or less glass, fills the spaces between the slender interlacing crystals of plagioclase feldspar, constituting a diabasic texture on a very small scale. Magnetite in crystals and irregular grains is often abundant in the midst of the augite or is included by it and less commonly by the feldspars in dendritic aggregates. Often larger crystals (phenocrysts) of the augite and feldspars produce a porphyritic texture, and hence a large part of the rock is a basalt-porphyry. Sometimes these phenocrysts are sprinkled with poikilitic inclusions of the other minerals and glass, and sometimes stellate aggregates of augite and feldspar indicate simultaneous crystallization (Plate XLVIII., Fig. 3). In the larger feldspars a zonal structure is not uncommon.

Near the bottom of the various sheets and their constituent flows, and near their vesicular or ropy upper surfaces grayish and brownish glass, sometimes highly spherulitic, becomes very abundant. It is usually thickly crowded with dust-like and minute dendritic magnetite crystals and unindividualized microlites (Plate XLV., Figs. 1, 2). With great increase of glass augite entirely disappears and minute feathery feldspar, often curved or in radiate and sheaf-like clusters is the only mineral present (Plate XLV., Fig. 3). On the outer surfaces of the ropy flow-structure there is often as much as 25 mm. (1 inch) of glass alone, as at West Paterson and Feltville. Among the felsdpars orthoclase is rarely recognizable. Scattering olivine crystals are some-

## EXPLANATION OF PLATE XLVI.

*Photomicrographs of thin sections.*

Fig. 1. GLASSY BASALT, *West Paterson.* Magnified 40 diameters. Typical diabasic texture of feldspars and augite in dark glass. Thin section No. 145–L.

Fig. 2. GLASSY BASALT, *same locality as Fig. 1.* Magnified 40 diameters. Texture in part diabasic, in part ophitic (feldspars inclosed in the larger augites), with abundant black glass. Thin section No. 118–L.

Fig. 3. GLASSY BASALT, *Scotch Plains.* Magnified 40 diameters. From the bottom "gray" layer, 15 to 20 feet thick. Typical ophitic texture. Thin section No. 34–L.

Fig. 1.

Fig. 2.

Fig. 3.

times present, although rarely abundant, and are usually altered wholly or in part to yellowish or greenish serpentine. Often much of the glassy base is also altered to greenish or yellowish serpentine, frequently with some chlorite, and sometimes it has been entirely replaced by granular calcite (Plate XLVIII., Figs. 1, 2,).

The alteration of augite is in part to fibrous uralitic hornblende (pleochroic, colorless or pale yellow to emerald green) or to chlorite or dirty brownish serpentine and granular magnetite or, in some cases, to a mixture of all these. In some localities, especially at Chimney Rock, near Bound Brook, parallel narrow bright red bands in the trap are found to be due to minute flakes of hematite (probably from augite) along several parallel zones near the joint-planes. The feldspars frequently show a more advanced stage of alteration than the augite, being clouded with kaolin-like material or partly replaced by calcite and analcite. Sometimes the feldspars and occasional olivine crystals as well as the glassy base, are entirely replaced by calcite.

Amygdules filling the bubble-cavities in the cellular varieties of the basalt are composed of radial or banded concentric calcite or of serpentine, chlorite and zeolites. Sometimes the cavity is lined with a film of quartz, calcite or feldspar or with metallic copper in parts of First Mountain (Plate XLIX., Fig. 1), and the rest of the space filled with serpentine. Veinlets of calcite, chlorite and serpentine, with sometimes a little hematite occasionally traverse the sections.

*Order of crystallization.*—Magnetite was the first mineral to form in the process of solidification, as shown by its constant presence as inclusions in the other minerals. Olivine, when present, is automorphic and must have crystallized among the first products, doubtless immediately following the magnetite. The feldspars, however, crystallized in a comparatively free liquid magma, and therefore do not include the magnetites in large numbers. The formation of augite, however, followed rapidly, and in filling the remaining space crowded the magnetite granules about its borders and included them in large numbers. But it is quite probable that much of the magnetite now seen is secondary and due to incipient alteration of the inclosing augite. The large porphyritic plates of augite and feldspar, like those in the basaltic contact facies of the Palisade diabase, are undoubtedly the begin-

## EXPLANATION OF PLATE XLVII.

*Photomicrographs of thin sections.*

Fig. 1. Basalt, *1 mile south of Short Hills.* Magnified 40 diameters. From the upper "gray" layer in Hartshorn's quarry. Predominant slender feldspars, granular and elongated augite and gray glass. Thin section No. 310–L.

Fig. 2. Glassy basalt, *same locality.* Magnified 45 diameters. From the middle "black" layer, showing the clear-cut feldspar laths, the granular augite and abundant nearly black glass. Thin section No. 308–L.

Fig. 3. Basalt, *same locality.* Magnified 40 diameters. From the bottom "gray" layer, showing the coarser texture, broad augites and stubby feldspars. Much of the glass is globulitic and considerably altered to greenish yellow serpentine. Thin section No. 309–L.

Fig. 1.

Fig. 2.

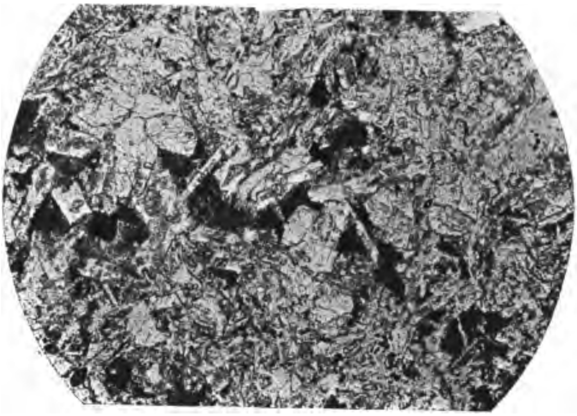

Fig. 3.

ning of a slower deep-seated crystallization in which augite was forming first. This was interrupted and the order of crystallization reversed by the eruption of the lava and its subsequent rapid cooling under very different physical conditions.

*Chemical composition.*—Chemically the basalts vary but little from the average composition of the diabase, as would be surmised from the identical mineral constitution and texture of the finer grained crystalline parts of the two types. The different sheets and the successive flows of which they are composed vary among themselves (Plate L.), but not to the extent that is found in the several differentiated types of the diabase.

*Analyses of Watchung Basalt.*

| | I. | II. | III. | IV. | V. | VI. | VII. | VIII. | IX. |
|---|---|---|---|---|---|---|---|---|---|
| $SiO_2$ ......... | 50.19 | 51.09 | 51.77 | 51.82 | 51.84 | 51.86 | 49.68 | 49.17 | 49.71 |
| $Al_2O_3$ ...... | 14.65 | 14.23 | 14.59 | 14.18 | 15.11 | 16.25 | 14.02 | 13.80 | 13.66 |
| $Fe_2O_3$ . .... | 3.41 | 2.56 | 3.62 | 0.57 | 1.78 | 2.14 | 4.97 | 4.90 | 5.49 |
| FeO ......... | 6.96 | 7.74 | 6.90 | 9.07 | 8.31 | 8.24 | 9.52 | 10.61 | 9.51 |
| MgO ........ | 7.95 | 7.56 | 7.18 | 8.39 | 7.27 | 7.97 | 5.80 | 5.04 | 6.13 |
| CaO ......... | 9.33 | 10.35 | 7.79 | 8.60 | 10.47 | 10.27 | 6.50 | 9.87 | 5.85 |
| $Na_2O$ ....... | 2.64 | 1.92 | 3.92 | 2.79 | 1.87 | 1.54 | 3.49 | 2.21 | 4.51 |
| $K_2O$ ......... | 0.75 | 0.42 | 0.64 | 1.26 | 0.34 | 1.06 | 1.41 | 0.54 | 0.37 |
| $H_2O+$ ...... | 2.38 | 1.01 | 1.85 | 1.40 | 1.33 | 1.33 | 1.89 | 0.73 | 2.66 |
| $H_2O-$ ..... | 0.66 | 1.66 | 0.46 | 0.30 | 0.56 | ...... | 0.54 | 1.04 | 0.48 |
| $TiO_2$ ......... | 1.13 | 1.30 | 1.13 | 1.17 | 1.22 | ...... | 1.39 | 1.50 | 1.53 |
| $P_2O_5$ ....... | 0.18 | 0.16 | 0.18 | 0.17 | 0.13 | ...... | 0.21 | 0.24 | 0.10 |
| MnO......... | 0.07 | 0.25 | 0.05 | 0.13 | 0.09 | 0.09 | 0.18 | 0.07 | 0.13 |
| | 100.30 | 100.25 | 100.08 | 99.85 | 100.32 | 100.28[1] | 99.60[2] | 99.75[3] | 100.13 |
| Sp. Gr...... | 2.92 | 2.936 | 2.91 | 2.95 | 2.93 | ...... | 2.949 | 2.997 | 2.91 |

I. Hartshorn's quarry, near Springfield and Short Hills. Lower "gray" layer. (Analysis No. 121, specimen and thin section No. 309-L.) R. B. Gage, analyst.

II. Same locality, middle "black" layer. (Analysis No. 120, specimen and thin section No. 308-L.) R. B. Gage, analyst.

III. Same locality, upper "gray" layer. (Analysis No. 122, specimen and thin section No. 310-L.) R. B. Gage, analyst.

IV. Hatfield & Weldon's quarry, Scotch Plains. Lower "gray" layer. (Analysis No. 130, specimen and thin section No. 35-L.) R. B. Gage, analyst.

V. Same locality, "black" rock above. (Analysis No. 131, specimen and thin section No. 36-L.) R. B. Gage, analyst.

VI. O'Rourke's quarry, West Orange. Large columns near the bottom. (Bull. U. S. Geol. Sur. No. 150, p. 255.) L. G. Eakins, analyst.

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[1] Including NiO 0.03.

[2] Trace of SrO.

[3] Including SrO 0.03.

# EXPLANATION OF PLATE XLVIII.

*Photomicrographs of thin sections.*

Fig. 1. GLASSY BASALT, *3 miles north of Somerville.* Magnified 30 diameters. From the bottom contact at the copper mine, showing fresh feldspar crystals and occasional augite, while the glassy base has been wholly replaced by calcite (compare Fig. 2). Thin section No. 205–L.

Fig. 2. GLASSY BASALT, *same as Fig. 1,* photographed with crossed nicols, showing the coarse granular texture and wavy extinction of the calcite replacing the glass.

Fig. 3. COARSE-GRAINED BASALT, ½ *mile southwest of Bernardsville.* Magnified 11 diameters. Stellate grouping of feldspar intergrown with augite. The latter is somewhat altered and appears very dark in the figure. Thin section No. 240–L.

Fig. 4. BASALT TUFF, *Towackhow or Hook Mountain, 1 mile north of Pine Brook,* from the tunnel of the Jersey City pipe line. Magnified 11 diameters. Black angular fragments of glassy basalt with interstices filled with radial colorless to brownish natrolite. Thin section No. 256–L.

Fig. 5. SHALE INCLUSION IN BASALT, *3 miles north of Somerville,* from the base of the basalt sheet at the copper mine. Magnified 11 diameters. Numerous scalenohedral calcite crystals are developed in the shale. Thin section No. 204–L.

Fig. 6. SHALE INCLUSION, *quarry* ¼ *mile south of Great Notch.* Magnified 11 diameters. A minute faulted dike of glassy basalt crosses the field. The glass has been entirely replaced by calcite, as in Figs. 1 and 2 above. Thin section No. 172–L.

Fig. 1.

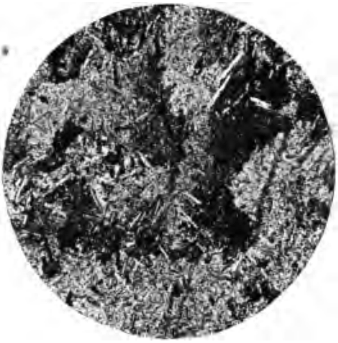


Fig. 2.

Fig. 3.

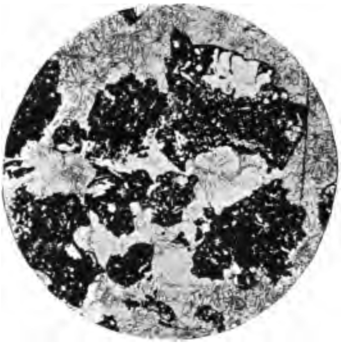


Fig. 4.

Fig. 5.

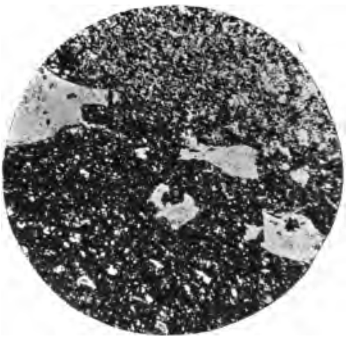


Fig. 6.

**VII. Morris County Crushed Stone Co.'s quarry, Millington. Lower "gray" layer. (Analysis No. 123, specimen and thin section No. 245-L.) R. B. Gage, analyst.**

**VIII. Same locality, middle "black" layer. (Analysis No. 124, specimen and thin section No. 246-L.) R. B. Gage, analyst.**

**IX. Same locality, upper "gray" layer. (Analysis No. 125, specimen and thin section No. 247-L.) R. B. Gage, analyst.**

Other analyses published in the earlier reports of this Survey and in the Twentieth Annual Report of the U. S. Geological Survey (Vol. VI., p. 419) are not sufficiently accurate or complete for present purposes.

The first five analyses above represent the lower "gray" (I., IV.), the middle "black" (II., V.), and the upper "gray" (III.) layers, respectively, of the First Mountain sheet. In these the alumina and iron (taking the ferric and ferrous together) are almost constant, and the silica shows only a slight increase upward. The characteristic differences appear in the variations of magnesia, lime and the alkalis, the magnesia decreasing upward, while the lime is highest and the alkalis the lowest in the middle layer (Plate L.). The ratios of lime to the sum of the soda and potash are also striking, namely, 3.32, 5.29 and 2.01 at Hartshorn's quarry, and 2.61 and 6.06 for the first and second layers at Scotch Plains.

No. VI. represents the large columns near the bottom of the quarry at West Orange (O'Rourke's), but chemically it clearly belongs to the second layer at the other localities. The first layer, which is always thin and quite variable, is here probably reduced to the thin platy layer at the contact with the sandstone or is absent altogether. On the other hand, if the whole sheet be regarded as the result of one continuous flow of lava, instead of successive flows or pulsations, this analysis simply means that the variations in chemical character of the basalt are not so regular as analyses I.-V. would seem to indicate.

Nos. VII.-IX. represent what appear to be separate layers of the basalt of Third Mountain (including Long Hill, Hook and Packanack Mountains) at Millington (Plate L.). As compared with the analyses of the First Mountain basalt, these are notably lower in silica, somewhat lower in alumina, magnesia and lime, but higher in soda and titanium and much higher in iron. The striking differences again appear in the magnesia, lime, soda and potash, particularly in the higher lime and the lower magnesia and soda in the second layer. The potash decreases upward and the

## EXPLANATION OF PLATE XLIX.

*Photomicrographs of thin sections.*

Fig. 1. Amygdaloidal basalt, *copper mine 3 miles north of Somerville.* Magnified 18 diameters. Unsymmetrical calcite amygdules, both radial fibrous and concentric banded, appear in the field. Metallic copper (black in the figure) lines some of the amygdaloidal cavities. Thin section No. 320–L.

Fig. 2. Amygdaloidal basalt, *same section as Fig. 1.* Magnified 18 diameters. The black veinlets are metallic copper.

Fig. 3. Bleached shale impregnated with metallic copper (black areas), *same locality as Figs. 1 and 2.* Magnified 18 diameters. Thin section No. 321–L.

Fig. 1.

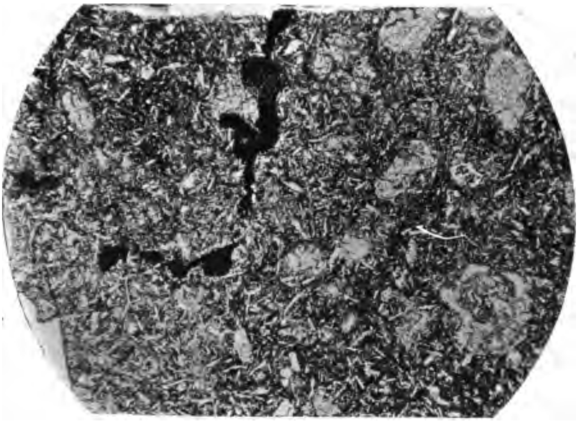


Fig. 2.

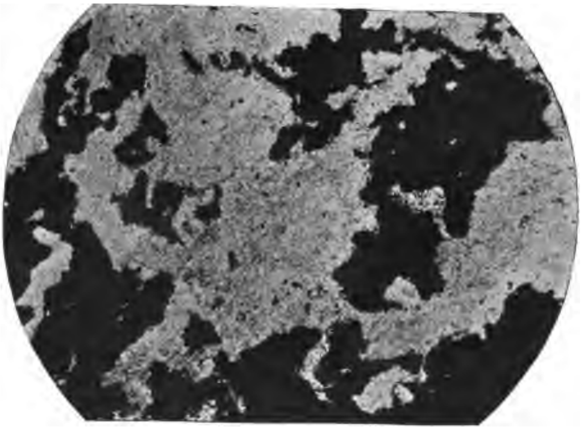
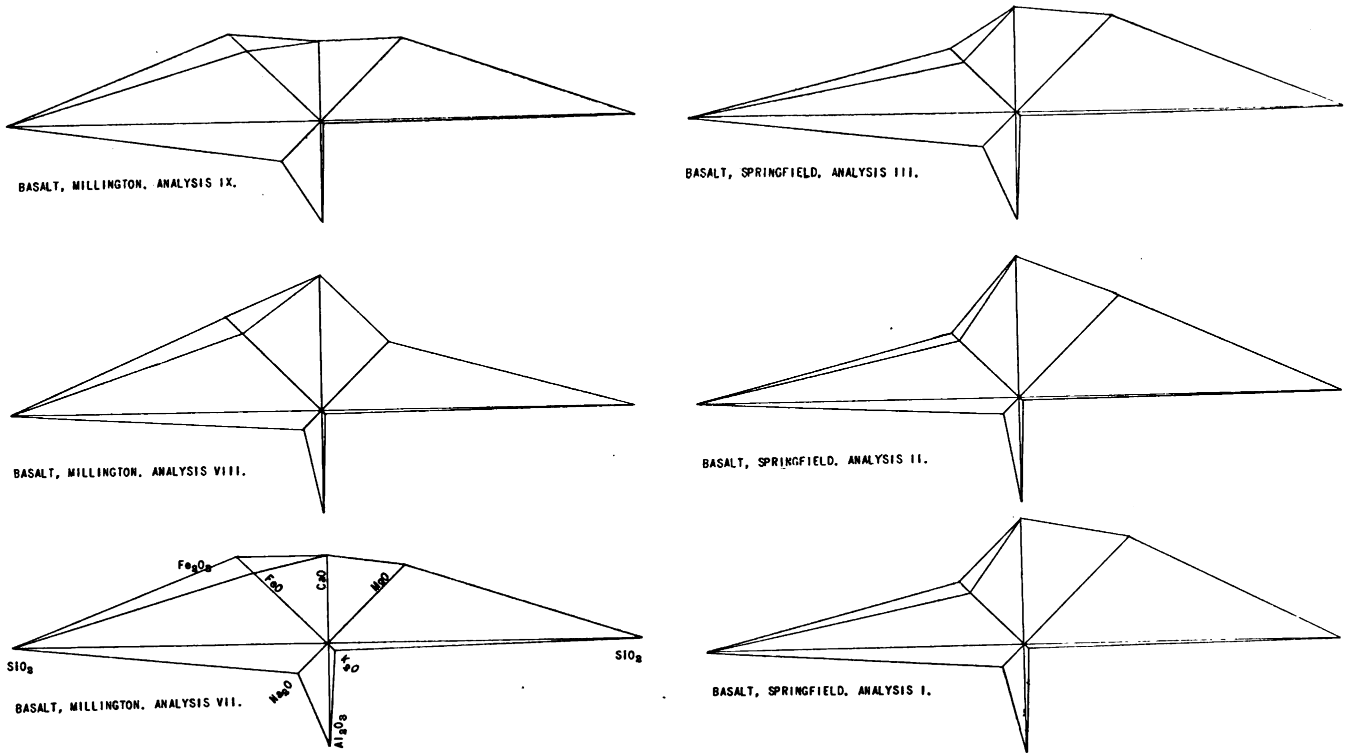


Fig. 3.

PLATE L.



BASALT, MILLINGTON. ANALYSIS IX.

BASALT, SPRINGFIELD. ANALYSIS III.

BASALT, MILLINGTON. ANALYSIS VIII.

BASALT, SPRINGFIELD. ANALYSIS II.

BASALT, MILLINGTON. ANALYSIS VII.

BASALT, SPRINGFIELD. ANALYSIS I.

Diagrams showing composition of different facies, possibly successive flows, of Third Mountain (Long Hill) at Millington and First Mountain at Springfield.

iron shows the opposite variation from magnesia. The ratios of lime to the sums of the soda and potash are 1.63, 4.42 and 1.36, respectively.

*Classification.*—In the older nomenclature these rocks are classed as *basalt,* or when visible crystals of augite are scattered through the groundmass of finer grained or glassy materials, as *basalt porphyry.* Both types are abundant, and in both the groundmass varies from holocrystalline to spherulitic and glassy, and in the latter cases it is often vesicular. The porphyritic type often contains occasional olivine crystals, and this mineral is sometimes sufficiently abundant to constitute an *olivine-basalt,* which corresponds to the olivine-diabase of the intrusives, although never so rich in olivine. On the other hand, no quartz-basalt, corresponding to the quartz-diabase of the Palisade sill, has been found.

Owing to the evident similarity between the basalts and diabases, in chemical, mineral and physical characteristics, they have often been grouped together under the name diabase, and still more commonly they are called simply "trap rocks."

In the quantitative system[1] all of the analyses are found to fall into Class III., Salfemane, and Order 5, Gallare. The distinctions appear, however, in their distribution between Rangs 3 and 4, as shown by the following summary:

*Summary of Classification of the Watchung Basalt.*

| *Name.* | *Symbol.* | *Analyses.* |
|---|---|---|
| Camptonose | III.5.3.4. | Nos. V, VII. |
| Ornose | III.5.3.5. | III, IX. |
| Auvergnose | III.5.4.4,5. | I, II, IV, VI, VIII. |

*Inclusions in the basalt.*—Small irregular masses of sandstone and shale, varying in size from microscopic dimensions to a maximum thickness of about 2 feet, have been observed in various parts of the extrusive basalts. They are usually not over 2 or 3 inches thick, however, and are chiefly confined to the bases of the sheets, within a few inches of the underlying strata, although this is not without exceptions. The smaller ones are baked into a hard jaspery condition and are usually a little darker in color. Since

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[1] Quantitative Classification of Igneous Rocks. By Cross, Iddings, Pirsson, and Washington. Chicago, 1903.

the contemporary origin of the Watchung basalts and the inclosing sediments has been well established, it has been recognized that the unconsolidated sand and mud over which the lava flowed were too incoherent to be taken up in large masses. Such parts as did become involved in the lava readily fell apart into small earthy clods during the continued flow.

The only inclusion noted of greater extent than 2 or 3 inches is exposed in the roadside near the dam at Pompton, in the trap of Packanack Mountain, a part of Third Mountain. Here an oval space, about 2 feet in diameter by 4 feet in length, has been hollowed out in the basalt from the almost complete crumbling away of the original sandstone contents. The portion that remains is friable and apparently entirely unaffected by the inclosing igneous rock. The possibility of later introduction of loose sands into a cavity here is to be borne in mind, especially as the inclusion is near the base of what appears to be a second flow of lava in the Third Mountain sheet. Inasmuch as this inclusion seems to be entirely isolated, however, it seems more likely that it was taken up from deposits over which the lava moved in some part of its course.

Thin sections have been prepared of a number of small shale inclusions in the basalt of First Mountain, chiefly from the base of the sheet at the Somerville copper mine. At the immediate contact the color of the shale is dark red, sometimes even brownish black, but this penetrates to a depth of only 2 or 3 mm. ($^1/_{12}$th to $\frac{1}{8}$th inch) and the color of the rest of the inclusion is the usual brownish red of the Brunswick shales. Accompanying the superficial color change there is a development of calcite, sometimes in relatively large scalenohedral (dog-tooth) crystals (Plate XLVIII., Fig. 5), and some crystalline calcite usually permeates the whole mass of the smaller inclusions. Crystalline quartz is also formed in some cases. Vein-like aggregates of these minerals and zeolites may be of contemporaneous origin from the action of vapors and heated waters excluded during the crystallization of the inclosing basalt.

In one section a faulted microscopic dike of glassy basalt penetrates the shale inclusion (Plate XLVIII., Fig. 6). In polarized light the glass is found to have been entirely replaced by calcite. (Compare Plate XLVIII., Figs. 1, 2).

*Contact effects of the basalt.*—In the sudden chilling of the base of the lava as it flowed over the surface of the country there was little time for the "baking" effects of metamorphism; hence we do not find the shale changed into dense hard hornfels, as we do about the large intrusive masses, and it is often impossible to detect any change whatever from the normal color, texture or hardness of the strata. Where any effect is noticeable it is only at the lower contact, since the overlying strata were deposited later than the lava sheets that they cover. Sometimes the underlying shale is found adhering firmly to the igneous rock and is noticeably harder and of deeper color at the immediate contact. These effects, however, scarcely extend as far as an inch into the shale in the majority of cases, and probably never more than 3 inches. Under the microscope the characters are identical with those of inclusions described above.

In many places beneath the basalt of First Mountain (but not under the other extrusives) the shale 1 to 2½ feet from the contact has been partially bleached by the leaching out of the iron coloring and rendered porous by the solution and removal of the numerous little crystals of calcite. In the spaces thus formed copper and chalcocite have been deposited, as at the old Bridgewater mine near Somerville and for 15 miles along the mountain to the northeast (Plate XLIX., Fig. 3). Nothing in any way comparable to this condition is found in connection with any other extrusive sheet of the State although the rocks of all are practically identical, nor, indeed, at any other part of the First Mountain sheet itself. These effects are not attributable to the influences of the overlying lava sheet, but have been produced by ore-bearing solutions, probably magmatic, that brought up copper from the slowly cooling intrusive sill below.[1]

*Origin of the zeolites.*—The origin of the secondary minerals is still under investigation, but observations in quarries, which penetrate to depths of 100 feet or more below the surface in some instances, point strongly to their formation entirely beyond the range of surface conditions. Meteoric waters are now dissolving and removing calcite and oxidizing the chlorite and other ferrous minerals. Furthermore, the secondary minerals seem to have been

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[1] J. Volney Lewis, Origin of the Newark Copper Ores. Annual Report of the State Geologist for 1906, pp. 156–164. Also Economic Geology, Vol. II., pp. 252–257, 1907; and Engineering and Mining Journal, October 12th, 1907, p. 688.

derived chiefly from the ropy glass, in the cavernous spaces of which they are found, and the conversion of much of the glass into a massive chloritic substance appears to be one of the results of the process.

Carbonated but not oxygenated water must have been the agent, and the most available, as well as most efficient supply, because highly heated, seems to be the magmatic or juvenile waters expelled from the great bulk of the basalt sheets during the crystallization of their anhydrous constituents. The high content of combined water still retained by the more glassy facies, even when little altered, seems to indicate the hydrous condition of the whole liquid mass at the time of extrusion. The fresh-looking glass sometimes found also gives off large quantities of water at a red heat. The hypothesis is therefore suggested that the formation of the bulk of the zeolites, calcite, quartz, hematite, chlorite, &c., took place during the cooling of the lava, through the agency of magmatic vapors and hot waters circulating through the cavities.

This or some similar mode of origin is also indicated by the universal presence of apophyllite and datolite in association with the zeolites. The former contains fluorine and the latter boron, and it is difficult to account for the widespread occurrence of these elements except through the emission of fumarolic vapors by the cooling lavas.

It is hoped that the study of these minerals and their relations may furnish evidence for somewhat more positive conclusions in the near future.

## OTHER EXTRUSIVE SHEETS.

No other extrusives comparable in extent with the great sheets of the Watchung area are found in the Newark or Triassic formation of the State. Smaller masses occur, however, at Flemington, New Germantown and Sand Brook. An oval area of basalt little more than one-fourth of a mile in diameter forms Prospect Hill, just west of the town of Flemington. It is highly vesicular on its upper surface, has had little if any effect on the adjacent shale, and is probably extrusive. There are several dikes in the vicinity and southward toward Sourland Mountain, and one of these is doubtless the source of this small lava flow. Some of these dikes which are somewhat discontinuous in outcrop, Kümmel has traced into direct connection with the great mass of the Palisade diabase that forms Sourland Mountain. It is probable, therefore, that this little flow is of the same age as the great intrusive sill, in fact merely a small part of it that reached the surface, and, therefore, probably later than the First Mountain basalt at least.[1]

Other small basalt areas that are unmistakably extrusive form the little semi-circular ridges at New Germantown and Sand Brook, and the smaller remnants at the center of the curve in each case. The relations are similar to those observed along the Watchung ridges, except that the sheets are much thinner, and it has been shown[2] that they may be reasonably supposed to represent portions of the flows that constitute First and Second Mountains.

April 1, 1908.

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[1] J. Volney Lewis, Age of the Intrusives. Bulletin Geol. Society of America, Vol. 18, pp. 209, 210, 1907.

[2] J. Volney Lewis, Annual Report of the State Geologist for 1906, pp. 115–117.

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